CLINE, PROUTY,
RICHART & WESTCOTT

Lateral Pressure of wet Concrete on Column Forms

Civil Engineering

B. S.

1914

LATERAL PRESSURE
OF
WET CONCRETE ON COLUMN FORMS

BY

LAWRENCE ALBERT CLINE
EDWIN CHESTER PROUTY
FRANK ERWIN RICHART
CLIFFORD HARPER WESTCOTT

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

1914

UNIVERSITY OF ILLINOIS

COLLEGE OF ENGINEERING

May 25, 1914.

I hereby recommend that the thesis prepared under my direction by LAWRENCE ALBERT CLINE, EDWIN CHESTER PROUTY, FRANK ERWIN RICHART, and CLIFFORD HARPER WESTCOTT entitled LATERAL PRESSURE OF WET CONCRETE ON COLUMN FORMS be accepted as fulfilling this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

C. B. McDaniel.

Assistant Professor of Civil Engineering.

Recommendation concurred in:

Ira O. Baker.

Head of the Department of Civil Engineering.

TABLE OF CONTENTS.

INDEX TO TABLES

INDEX TO PLATES

INDEX TO FIGURES

LATERAL PRESSURE OF WET CONCRETE ON COLUMN FORMS.

I. INTRODUCTION.

1. Statement of Problem: The great development in the use of concrete, both plain and reinforced, for buildings, bridges, and similar structures has caused a great deal of labor and expense in the construction of suitable forms. In some cases these forms may be used several times but generally they are used only once. In any case, the cost of form work has become a large item in the expense of concrete construction, and is often as much as fifty per cent of the cost of the materials used. Any possible reduction in the amount of lumber used will effect a considerable saving in the total cost of extensive work.

It is the purpose ofthis thesis to make an investigation to determine the behavior of wet concrete in column forms. In this work the maximum lateral pressure exerted is of primary importance in order that the forms may be economically designed.

2. Available Data.- At present there is little information concerning the actual lateral pressure which wet concrete exerts upon forms. Several experiments have been made with widely varying results. A very extensive set of tests was made in 1908 by Major F. R. Shunk, an army engineer, during the construction of the Mississippi River Lock No. 1, near Minneapolis. His experiments, lasting throughout the season, were made on monolithic blocks of concrete 25.75 feet high, each of which was poured in a single day. The concrete mixture was 1:3:5 1/2, and was very wet. The forms were water tight. Lateral pressures were measured with

a rather crude apparatus consisting of a circular disk or piston connected to a scale beam. The results indicated that a hydrostatic pressure corresponding to a liquid weighing 152 pounds per cubic foot was obtained at first, but as the head increased, the concrete began to act more as a solid and the pressure remained almost constant. The point at which the concrete acted as a solid varied with the temperature, pressure, and condition of agitation of the material. It was also found that the concrete acted as a solid sooner when the rate of pouring was rapid, due to the earlier protection from the agitation of the surface.

Another very interesting test was conducted in 1913 by Mr. E.B.Germain, engineer for the Aberthaw Construction Company of Boston. Tests were made on columns twenty inches square and twenty feet high. A 1:1 1/2:3 mixture was used and the results agreed very well with those of Major Shunk. A hydrostatic pressure due to a liquid weighing from 140 to 150 pounds per cubic foot was found.

In contradiction to these results, several other experiments indicate that a lateral pressure of from 65 to 80 pounds per square foot per foot of head was produced. Undoubtedly the reason for such variation lies in the fact that different consistencies and varied rates of pouring were used.

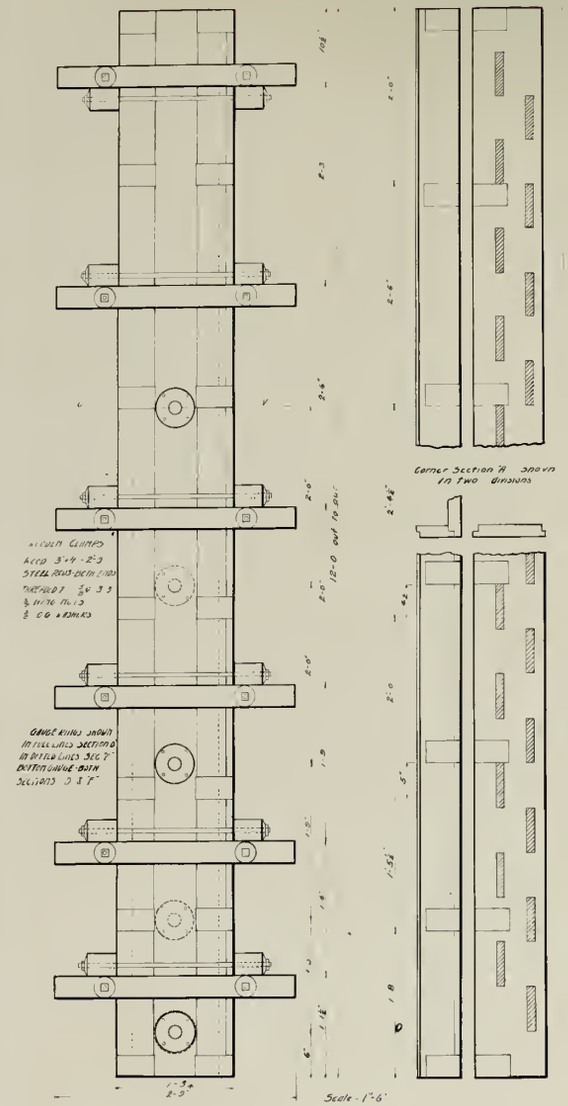
In designing forms it is common practice to consider the maximum pressure as that of a liquid of the same weight as concrete, although frequently sizes are used which have previously proven strong enough. The latter method is certainly erroneous on the side of safety, but is uneconomical.

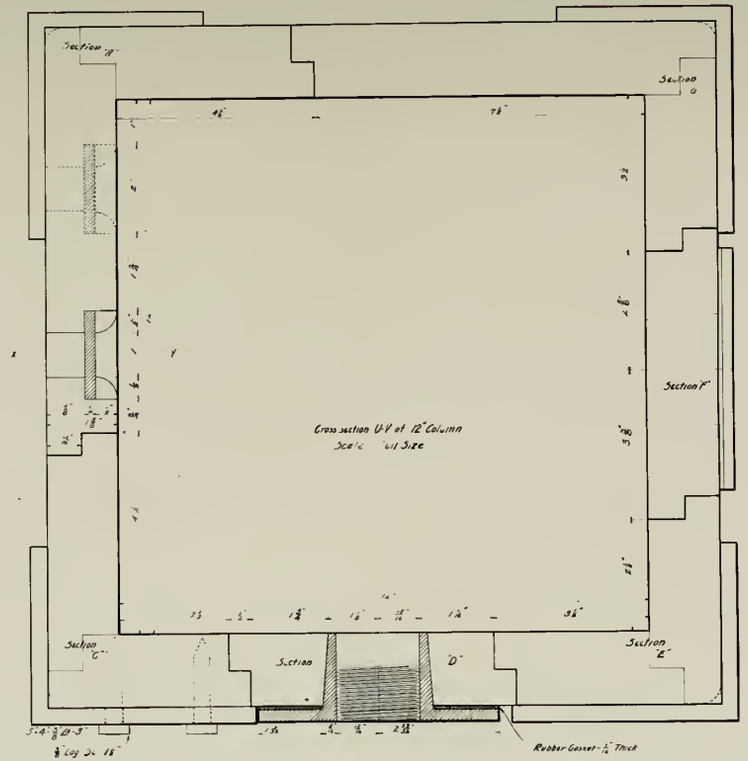
A definite knowledge of the pressures which are encountered in concrete pouring would be of value to engineers and contractors in designing forms, both in respect to strength and to rigidity. The increasing use of steel forms presents a problem where very efficient designing can be done if the maximum pressures are known.

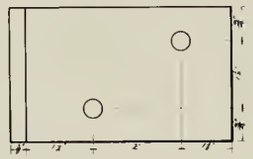
3. Plan of Investigation.- Plans were made to pour several columns twelve feet in height, varying from one to two feet square, and to record the lateral pressures exerted by means of mud gauges inserted in the column forms at various heights. By mixing the concrete in one large batch and raising it to the top of the form in a bucket, suspended from a traveling crane, continuous pouring was to be secured. The height of the concrete at any instant was to be read thru narrow wire glass windows in one side of the column. From these data the maximum pressure corresponding to any head of concrete was to be determined, and a study made of the general behavior of the material.

II. DESCRIPTION OF APPARATUS.

1. Column Forms.- The column forms were made of plank with ship-lap joints, the sections being interchangeable for the different sizes of forms. Square forms for twelve, sixteen, twenty, and twenty-four inch columns were made, the larger sizes being secured by adding four inch sections to the twelve inch size. Plate I shows the twelve inch size as used. The arrangement of sections for the different columns is shown in Plate II . The wooden clamps and rods were designed and spaced by assuming a pressure of an equivalent fluid weighing 150 pounds per cubic foot.



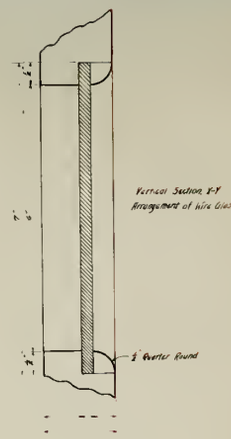


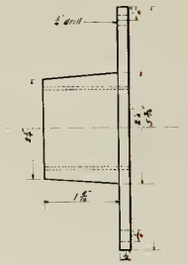


5'-0" - 3/4" Mipfe - 3"
Both legs punched in same way for 3/4" leg screws
Holes 7/8" in diameter

Bill of Materials.

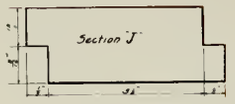
No pcs	Section	Dimensions	Notes
1	Corner - C	12' long	1/8" thick - 2 Display joints - glass inserts
1	" A		
1	" E		
1	" G		
1	Gauge Sec. D	6" wide	
1	" F		
1	" H	10"	For 16 & 24 cm
1	" I		
10	Section J	4"	
	Quarter round	40 lineal ft	1/2" radius
24	Clamp plates	3'-4" x 2-3	
24	Clamp rods	5/8" ø - 3'-3"	Threaded 1" each end
40	Wing nuts	5/8" - a	
48	Std Washers	for 5/8" rod	
28	Angles	3-4" x 4" - 3"	Stiffeners for corner
112	Leg Screws	3/8" - 1 1/2" long	For Bolts
24	Battenboard	3/4" - 12"	Gauge rings.
	Nails	10 d	For Corners
6	Rubber gasket	1/4" - Diams -	As 8-3/8" For gauge rings
4	Gauge rings	Furnished To	be set by contractor
22	Wire glass strips		
	Keystone Grease		





C I Gauge Ring

Gauge rings and wire glass sections to be put in with Keystone grease. Furnished by the University and set in the forms by contractor



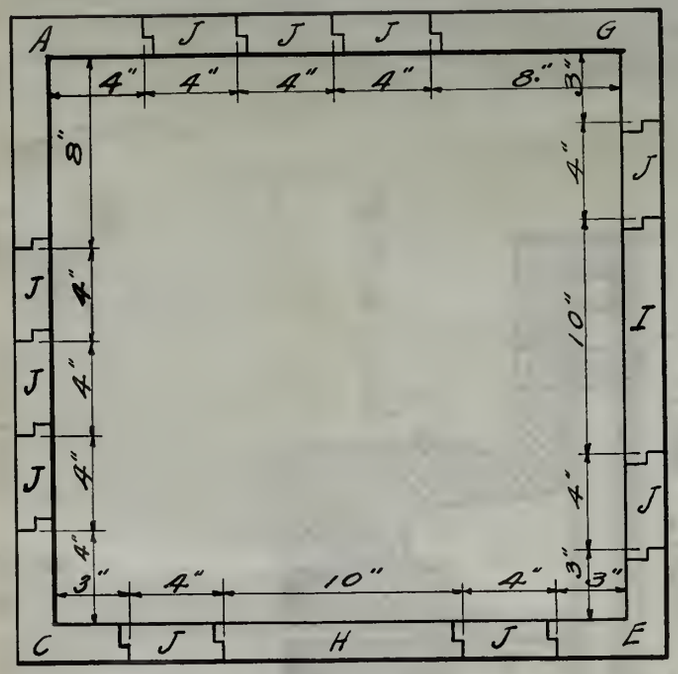
CONCRETE COLUMN FORMS.
Thesis Work
DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY of ILLINOIS.

L. A. Cline
E. C. Prouty
R. E. Burnett
C. H. Westcott

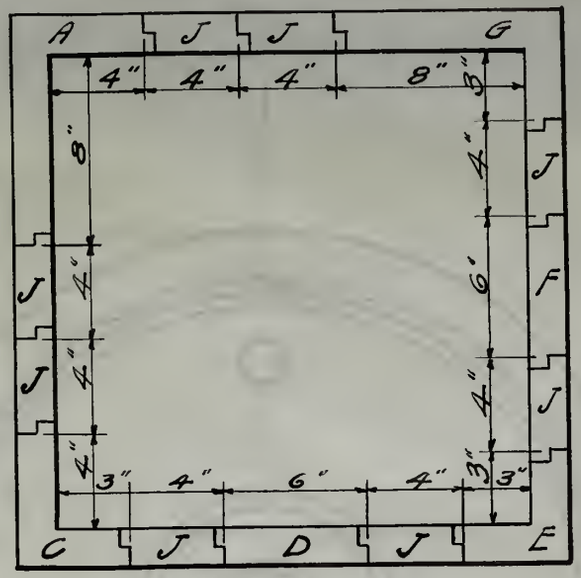
December 1, 1913
First Semester

Plate I.

24" Column.

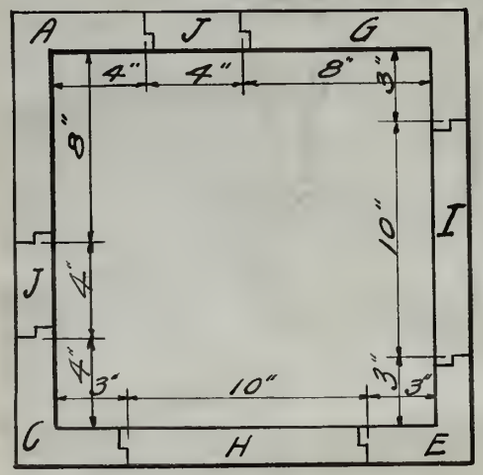


20" Column.



Scale-1"-8"

16" Column.



12" Column.

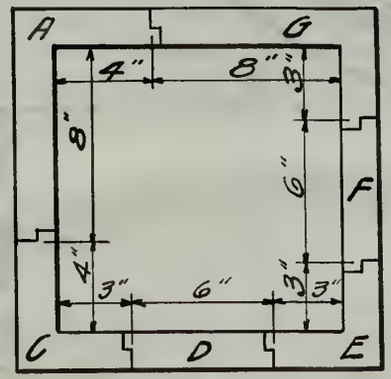


DIAGRAM of COLUMN FORMS

Thesis Work

DEPT. of CIVIL ENGINEERING

UNIVERSITY of ILLINOIS

L.A. Cline.
E.C. Prouty.
F.E. Richart.
C.H. Westcott.

December 5, 1913.

First Semester.

3/5

Plate II.

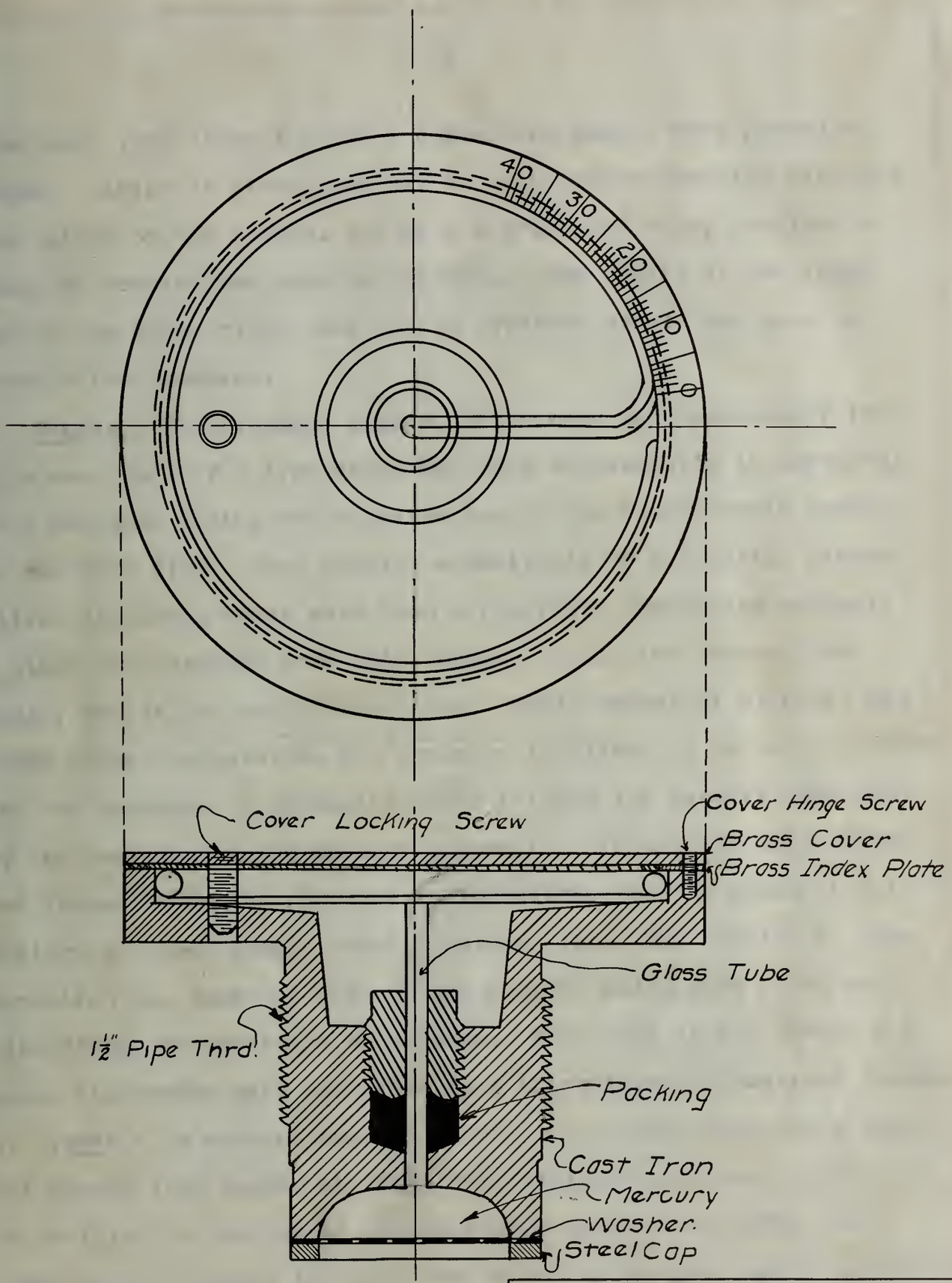


Plate III.

PRESSURE GAGE
THESIS WORK

University of Ill.

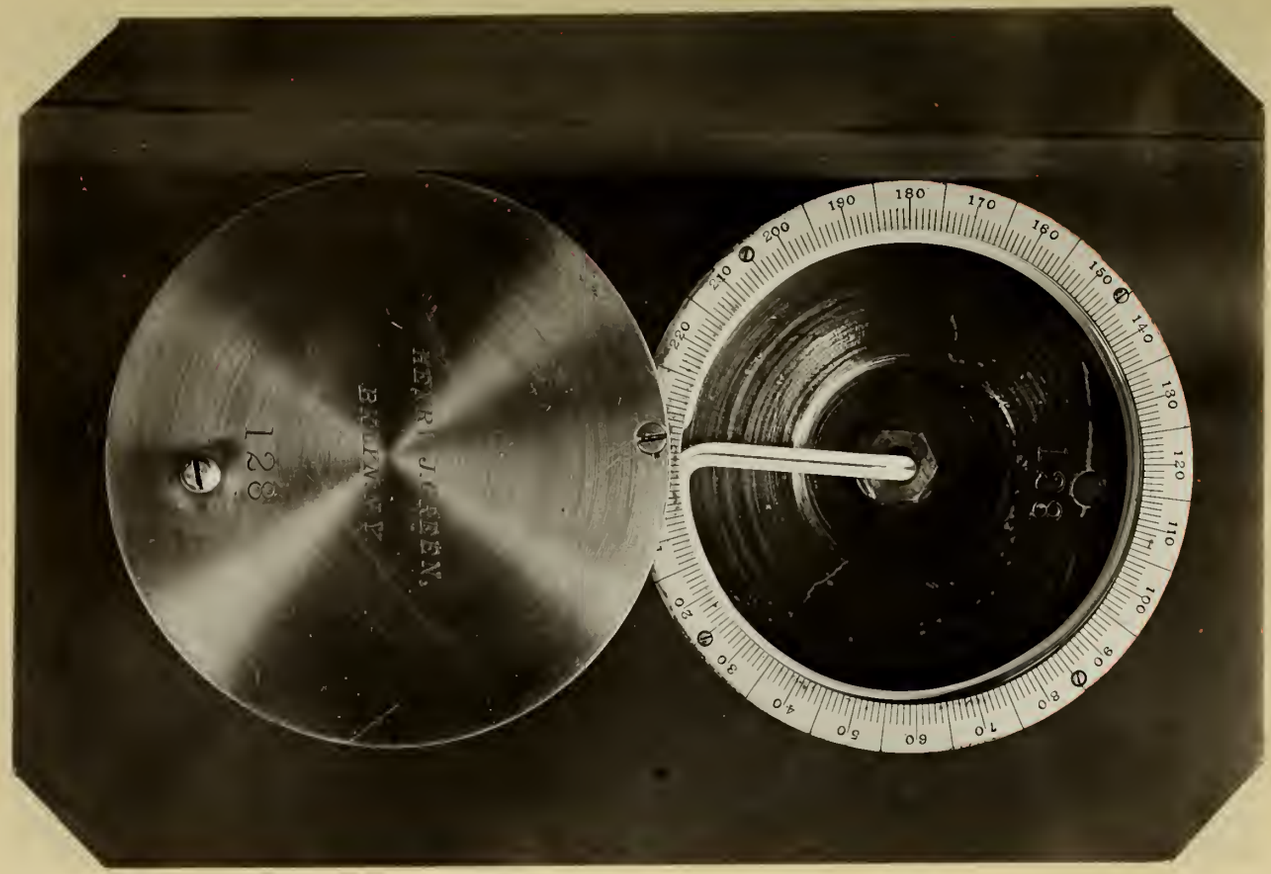
L.A. Cline
E.C. Prouty
F.E. Richart
C.H. Westcott.

5/5

Five cast iron rings to hold the pressure gauges were placed as shown. Strips of wire glass set in slots in one section extended the height of the column, and with a graduated tape, provided a means of reading the head of concrete. The joints of the forms and of the gauge rings were set in Keystone grease and gave no trouble from leakage.

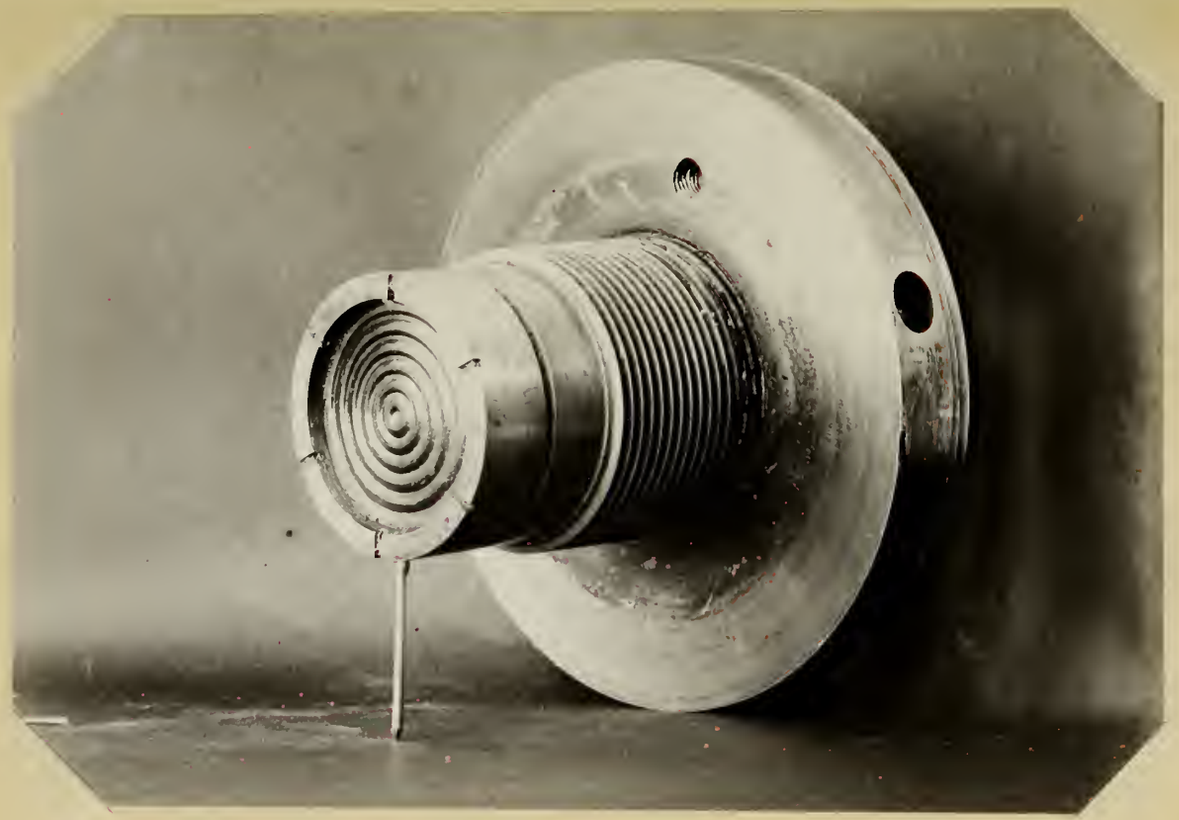
2. Gauges. The pressure gauges, which were made especially for this work, are of a type which was used successfully in measuring soil pressure during the construction of the Pennsylvania Tunnel in New York City. They consist essentially of a flexible German silver diaphragm which acts upon a reservoir containing mercury. A glass tube extends from this chamber around the face of the gauge, and in the end of this tube a small amount of nitrogen gas under normal temperature and pressure is placed to act as a cushion for the mercury. A graduated scale follows the mercury tube and by the position of the mercury column in reference to this scale the intensity of the pressure is indicated. As the graduation is arbitrary, these gauges require calibration. The details of construction are shown in Plate III and Figs. 1 and 2 show front and side views, respectively of a gauge. When used in the tests, the gauge diaphragms were protected by a thick layer of Keystone grease.

3. Tower.- A wooden tower to support the column form and a funnel shaped iron hopper above it were designed as shown in Plate IV. In addition to the weight of the hopper full of concrete, the tower was calculated to carry the weight of several observers during the test. The iron hopper was made to direct the stream of concrete from the bottom-dump bucket to the center of the column



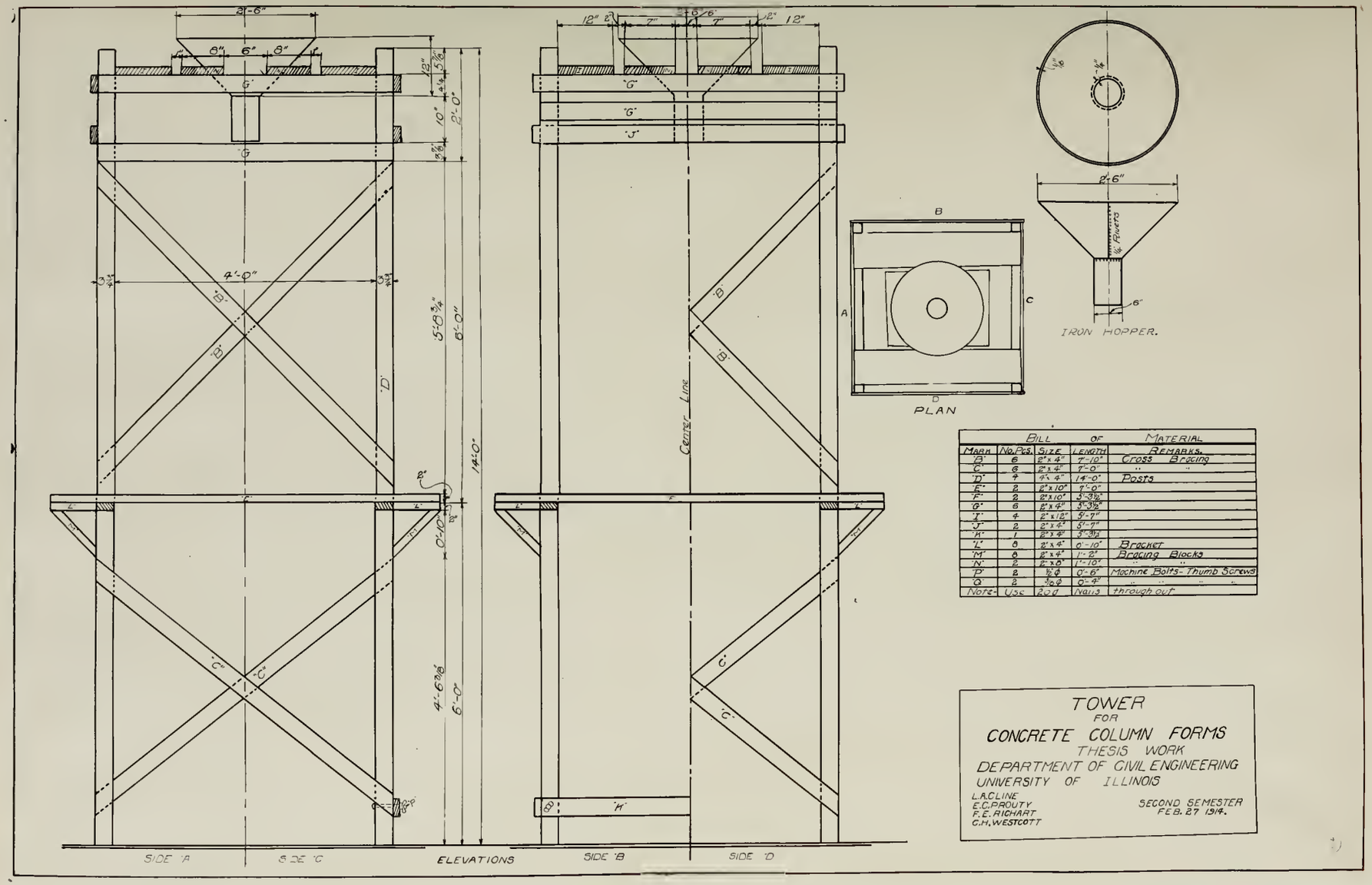
Front View of Mud Gauge

Figure No.1.



Rear View of Mud Gauge

Figure No.2.



Bill of Material				
Mark	No. Pcs.	Size	Length	Remarks
'B'	6	2" x 4"	7'-10"	Cross Bracing
'C'	6	2" x 4"	7'-0"	" "
'D'	4	4" x 4"	14'-0"	Posts
'E'	2	2" x 10"	7'-0"	
'F'	2	2" x 10"	5'-3½"	
'G'	6	2" x 4"	5'-3½"	
'I'	4	2" x 12"	5'-7"	
'J'	2	2" x 4"	5'-7"	
'H'	1	2" x 4"	3'-3½"	
'L'	8	2" x 4"	0'-10"	Bracket
'M'	8	2" x 4"	1'-2"	Bracing Blocks
'N'	2	2" x 6"	1'-10"	" "
'P'	2	½ ϕ	0'-6"	Machine Bolts - Thumb Screws
'Q'	2	½ ϕ	0'-4"	" " " "
Note-	Use	200	Nails	through out

TOWER
FOR
CONCRETE COLUMN FORMS
THESIS WORK
DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ILLINOIS

L.A.CLINE
E.C.PROUTY
F.E.RICHART
C.H.WESTCOTT

SECOND SEMESTER
FEB. 27 1914.

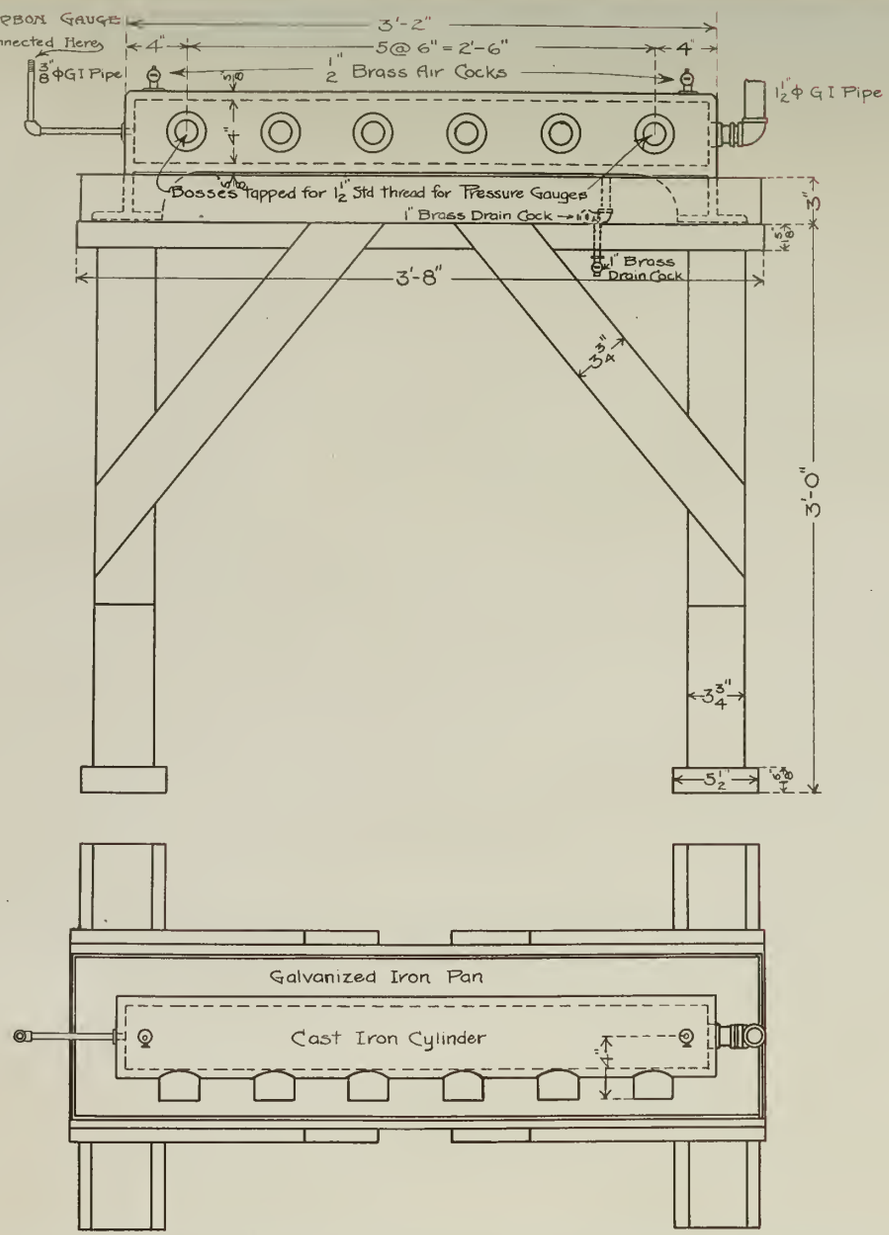
Plate IV.

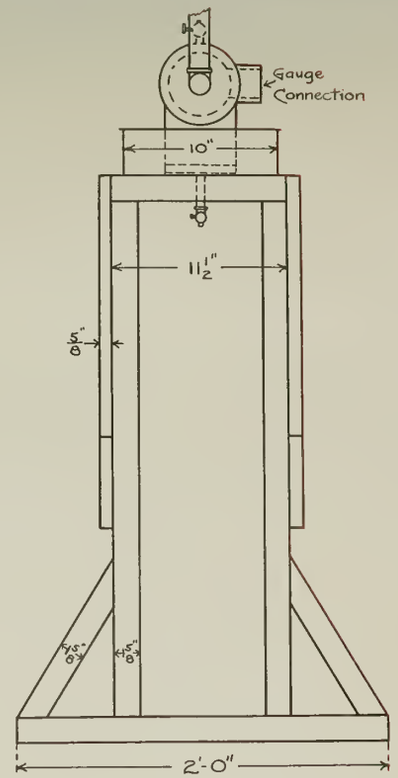
form. It was thought advisable to keep the concrete, in dropping thru a maximum distance of thirteen feet, from striking against the sides of the forms and thus possibly causing damage to the gauges, and the hopper was designed toward this end. It was easily removable, so that the column form could be lifted at the completion of each test in order to remove the concrete before it set. Fig. 5 shows the arrangement of the tower, column and bucket. The bracing on the front of the tower was made removable so that the column forms could easily be dismantled and erected.

4. Bucket.- The bucket was a sheet-steel coal bucket of the bottom-drop type, having a capacity of about eighteen cubic feet. On the top of it rested a wooden extension which increased the capacity to forty-eight cubic feet, the capacity of the twenty-four inch column. The bucket was suspended from a five-ton hand-power traveling crane which is installed in the concrete Testing Laboratory of the Engineering Experiment Station. The wooden addition to the bucket was well braced by horizontal rods and anchored thereto by vertical rods which supported the entire load.

III. PROCEDURE.

1. Calibration of Gauges.- The first experimental work was that of testing and calibrating the pressure gauges. A special, hollow, cylindrical casting was made by the Burr Company of Champaign, Ill., and was so arranged that all the gauges, together with a Bourdon Pressure Gauge, could be subjected simultaneously to the same water pressure. Calibration work was done in the Laboratory of Applied Mechanics, and water pressures varying from zero to twenty-three pounds per square inch were obtained by use of the





CAST IRON GAUGE TESTER
AND
WOODEN STAND
THESIS WORK

DEPT OF CIVIL ENGINEERING

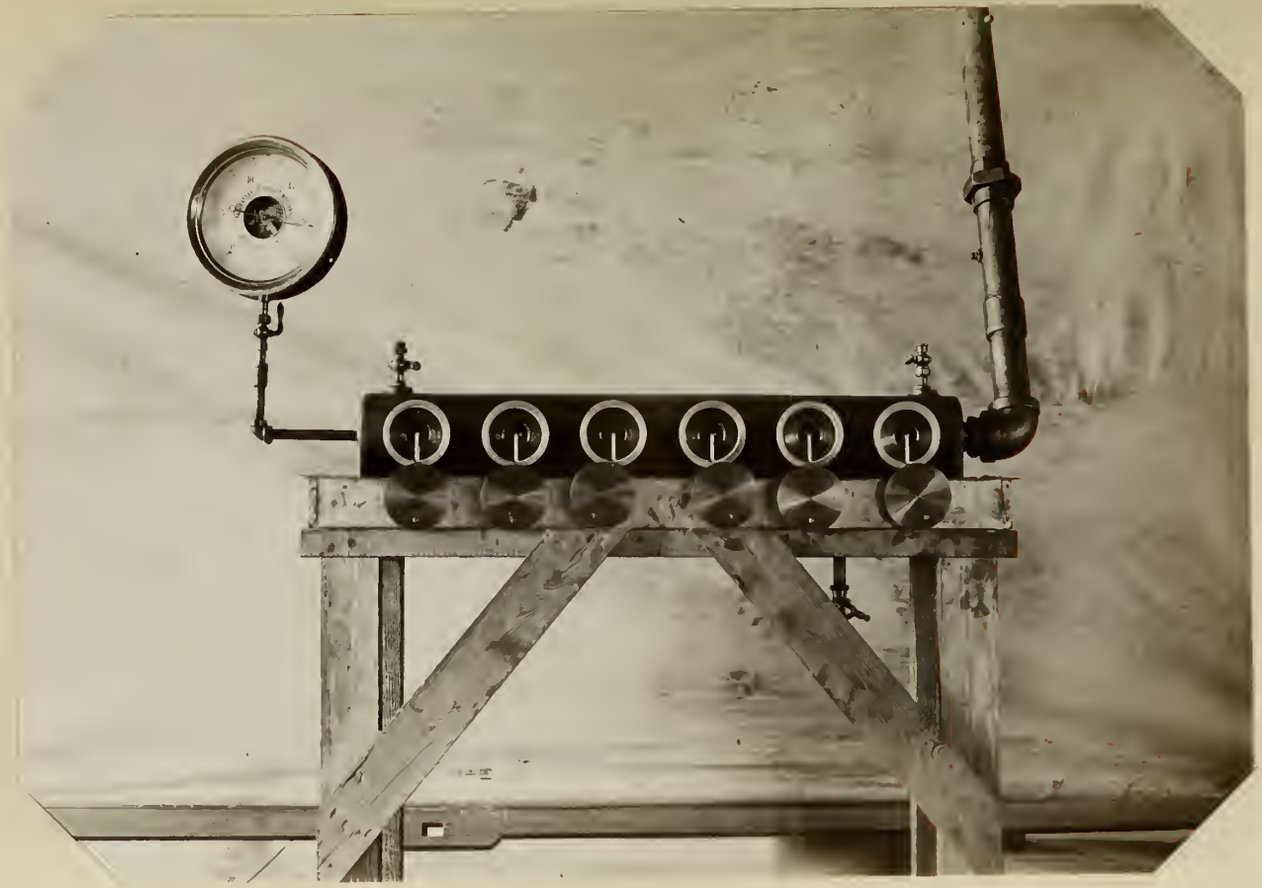
UNIVERSITY OF ILLINOIS

L A CLINE
E C PROUTY
F E RICHART
C H WESTCOTT

FEB 26 1914

SECOND SEMESTER

Plate V.



Calibration Apparatus

Figure No.3.

Table No. 1.

Calibrations of a Bourdon Pressure Gage.

No. of Gage---------- ---- ---

Area of Piston ----------0.2 Sq. in.

Weight of Piston ---- ---- 1.5 lb.

Pressure of Piston ---- ---- ---- lb. per sq. in.

Dec. 8, 1913. Dec. 7, 1913. Dec. 15, 1913. Jan. --, 1914.

Gal. No.	Gage. lb. per sq. in.	Gage. lb. per sq. in.	Gage. lb. per sq. in.	Gage. lb. per sq. in.	Gage. lb. per sq. in.	Gage. lb. per sq. in.	Gage. lb. per sq. in.	Gage. lb. per sq. in.
1	5.0	5.0	5.4	5.0	5.0	5.0	5.0	5.0
2	10.0	10.0	9.4	9.0	10.0	7.5	9.0	7.5
3	15.0	15.0	14.6	14.0	15.0	15.0	15.0	15.0
4	20.0	20.0	19.6	19.1	19.0	19.0	19.0	19.0
5	24.8	24.8	24.0	24.0	24.0	24.0	24.0	24.0
6	30.0	30.0	29.6	29.1	29.0	29.0	29.0	29.0
7	34.8	34.8	34.0	34.0	34.0	34.0	34.0	34.0
8	39.8	39.8	39.6	39.1	39.0	39.0	39.0	39.0
9	5.0	5.0	22.6	22.0	22.0	22.0	22.0	22.0
10	8.0	7.5	21.6	21.1	21.0	21.0	21.0	21.0
11	10.0	10.0	19.6	19.0	19.0	19.0	19.0	19.0
12	14.0	14.5	16.6	16.1	17.0	16.5	16.5	16.5
13	15.0	15.0	14.6	14.0	14.0	14.0	14.0	14.0
14	17.0	17.5	11.6	11.0	8.0	7.5	9.0	7.5
15	20.0	20.0	9.0	8.6	5.6	5.0	5.0	5.0
16	22.9	22.5	6.7	6.1				
17	20.0	20.0	5.0	5.0				
18	18.0	17.5						
19	15.0	15.0						
20	12.0	12.5						
21	10.0	10.0						
22	8.0	7.5						
23	5.0	5.0						

Table No. 2.

Calibration of Mud Gauges.

Temperature of Room- --72.0 F. Jan 15, 1914.

Ref. No.	457 lb. per sq. in.	709 ft.	130	128	120	00	127	06
1	0.0	44.8	31.0	63.5	64.0		63.0	63.0
2	18.4	43.2	102.0	120.0	114.5	85.0	110.5	119.0
3	18.0	42.0	100.0	118.0	115.5	82.0	109.0	118.0
4	16.9	39.0	96.5	115.5	110.0	78.0	106.5	115.5
5	15.9	37.5	93.0	114.0	107.5	74.0	104.0	112.0
6	14.9	35.5	90.0	110.5	105.0	70.5	102.0	110.0
7	13.9	33.5	87.0	108.0	103.0	67.0	100.0	108.0
8	13.0	31.0	83.5	106.0	100.0	63.0	96.0	105.0
9	11.8	28.0	78.5	102.5	97.0	58.0	92.0	102.0
10	10.9	26.0	75.5	100.0	95.0	55.0	89.0	99.0
11	10.0	24.0	71.5	96.0	92.0	50.0	86.0	96.0
12	9.1	22.0	68.0	93.5	89.0	46.5	83.0	92.5
13	8.1	20.0	64.0	90.5	86.0	41.5	80.0	89.0
14	6.8	17.0	59.5	86.0	83.0	34.0	81.0	84.5
15	5.7	15.0	54.0	82.0	79.5	29.0	77.0	81.0
16	5.0	12.9	51.0	80.0	77.0	25.5	76.0	79.5
17	4.0	10.3	46.0	77.0	74.0	20.0	73.0	74.5
18	2.9	8.0	42.0	75.0	71.5	12.0	69.0	72.0
19	2.1	6.0	39.0	71.0	68.0	10.0	66.0	69.0
20	1.0		34.0	67.0	65.0	4.5	64.0	67.0
21	0.0		32.0	65.0	63.0	4.0	62.5	65.0

Table No. 3.

Calibration of Mud Gauges.

Temperature of Room----------73.0 F. February 5, 1914.

Ref. No.	457 lb. per sq. in.	709 ft.	130	128	129	60	127	56
1	0.0	45.0	31.0	66.0	65.0	3.0	65.0	71.0
2	19.2	45.0	104.5	123.0	117.0	89.5	113.0	123.0
3	18.2	43.0	103.0	121.5	114.5	86.0	111.0	121.0
4	17.2	40.5	98.0	118.0	112.0	82.0	108.5	118.5
5	16.0	38.0	95.0	116.0	109.0	78.0	106.5	116.0
6	15.0	36.0	91.5	114.0	107.0	74.5	104.5	113.5
7	14.2	34.0	88.0	111.0	105.0	70.5	102.5	111.0
8	13.2	31.5	85.0	108.0	103.0	67.5	100.0	109.0
9	12.0	29.0	80.0	105.0	99.0	62.0	97.0	105.0
10	11.0	27.0	76.5-	102.0	97.0	57.0	94.0	102.0
11	10.0	25.0	73.0	98.5	93.5	52.5	92.0	99.5
12	9.1	22.5	68.5	95.5	91.0	48.0	89.0	96.0
13	7.8	19.5	63.0	91.5	87.5	42.0	85.5	92.0
14	7.1	17.5	60.0	89.0	85.0	38.5	83.5	89.5
15	6.1	16.0	56.0	86.5	82.0	34.0	81.0	87.0
16	5.0	12.5	50.5	82.5	78.5	28.0	77.5	82.5
17	4.0	10.5	46.5	79.0	75.5	23.5	74.5	79.0
18	2.9	8.0	42.0	75.0	73.0	17.0	71.5	75.0
19	2.2	6.0	39.0	73.0	72.0	12.0	69.0	72.5
20	1.1		34.0	69.0	69.0	7.0	66.0	68.0
21	0.5		33.0	68.5	68.5	5.0	65.5	68.0

Table No. 4.

Calibration of Mud Gauges.

Temperature of Room------75.0 F. February 6, 1914.

Ref. No.	457 lb. per sq. in.	709 ft.	130	128	129	127	56	60
1	0.0	0.0	30.0	69.0	65.0	64.5	65.5	6.0
2	18.2	43.0	101.0	121.5	114.0	111.0	120.5	89.0
3	16.4	38.5	95.0	117.5	109.5	107.0	117.0	82.5
4	15.0	35.0	90.5	114.5	106.5	104.5	113.5	78.0
5	13.5	32.0	85.0	109.5	102.5	100.5	110.0	71.5
6	11.8	27.8	78.5	105.5	98.0	96.5	104.5	64.0
7	10.8	26.0	74.5	102.0	95.0	94.0	101.5	59.5
8	9.6	23.0	70.0	98.0	92.0	90.5	97.5	54.0
9	8.4	20.3	65.0	95.0	88.5	87.5	94.5	49.5
10	7.2-	17.5	60.5	91.5	85.0	84.5	90.5	44.0
11	5.3	13.5	52.0	85.0	79.5	79.0	83.5	36.0
12	4.4	10.5	48.0	82.5	76.0	76.5	81.0	32.5
13	3.2	8.0	43.0	78.5	73.0	73.0	76.0	27.5
14	2.2		39.5	75.0	71.0	70.5	72.5	2[illegible].0
15	1.0		34.5	71.5	69.0	67,5	69.5	14.0

Table No. 5.

Calibrations of Mud Gauges.

Temperature of Room-------64.5 F. February 7, 1914.

Ref. No.	457 lb. per sq. in.	709 ft.	130	128	129	127	56	60
1	0.0	0.0	26.5	66.5	40.5	64.0	64.5	16.0
2	20.0	47.0	104.0	127.0	105.5	116.0	126.0	92.5
3	18.0	42.0	97.0	122.0	100.5	111.5	122.0	87.0
4	15.8	37.0	89.0	117.5	93.5	106.5	117.0	73.0
5	13.9	33.0	82.0	112.5	88.5	102.5	111.5	72.0
6	11.4	27.0	72.0	104.5	80.0	96.0	104.5	60.0
7	9.4	23.0	64.0	99.5	73,5	91.0	99.5	51.5
8	8.2	20.0	58.5	95.0	70.5	87.0	95.0	46.5
9	6.8	16.0	54.0	90.5	65.5	83.5	90.5	39.5
10	5.2	13.0	47.0	85.0	61.0	79.0	85.0	33.0
11	4.2	10.0	43.0	81.5	55.0	76.5	81.0	28.0
12	3.2	8.0	39.0	77.5	50.5	73.0	76.5	22.5
13	2.1		33.5	74.5	47.5	70.0	74.0	17.5
14	1.2		29.0	72.0	43.0	67.5	69.5	12.0

Tacle No. 6.

Calibration of Mud Gauges.

Temperature of Room-----66.0 F. February 7, 1914.

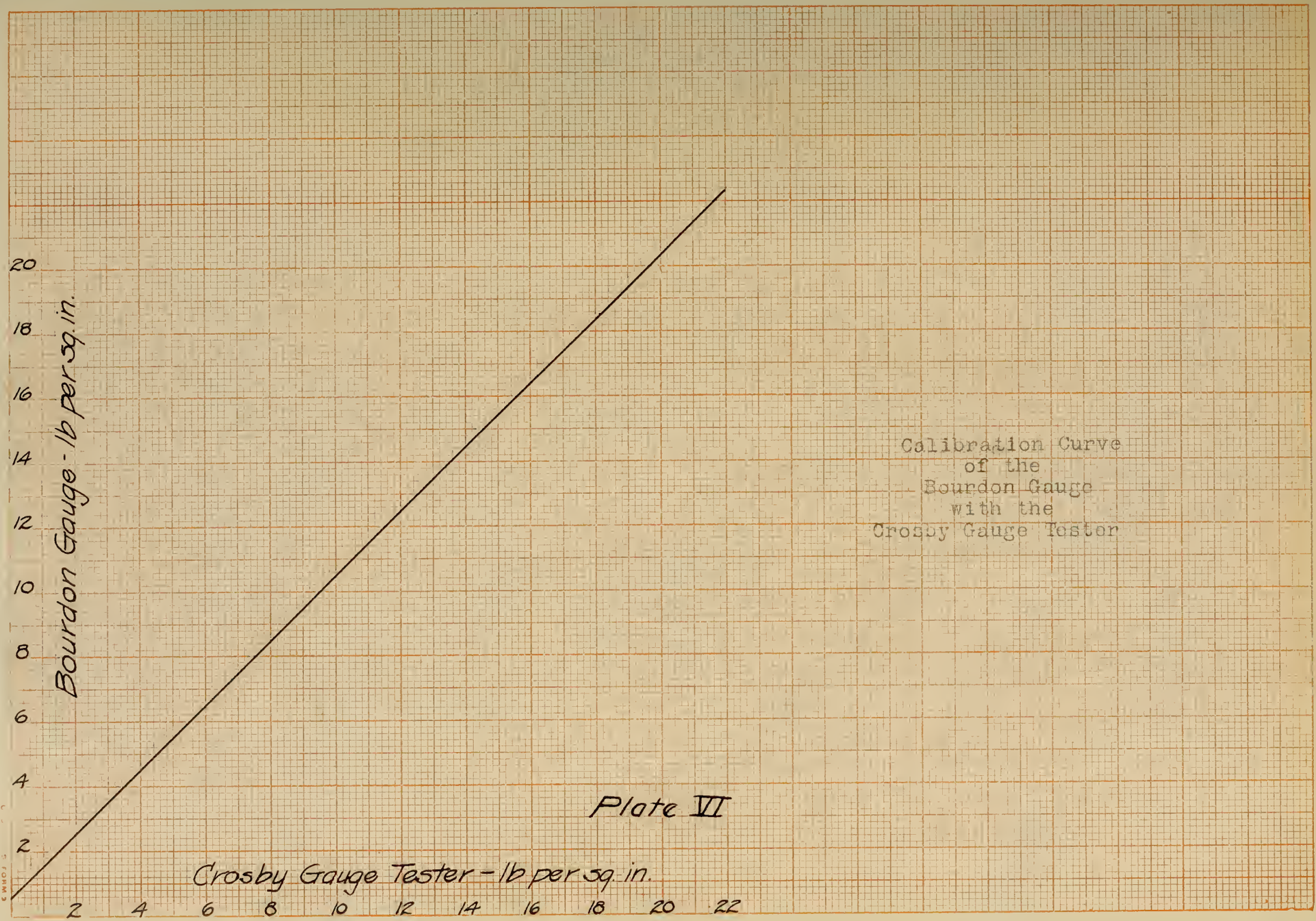
Ref. No.	457 lb. per sq. im.	709 ft.	130	128	129	127	56	60
1	0.0	0.0	30.0	62.5	65.0	64.5	64.5	7.0
2	20.0	47.0	106.0	127.0	119.0	115.0	126.0	94.0
3	18.2	42.5	101.0	123.0	114.5	111.0	122.0	88.0
4	16.0	37.5	94.0	117.5	109.0	107.0	116.5	80.0
5	14.0	33.0	87.0	112.5	104.5	102.0	111.5	74.0
6	11.9	28.0	80.0	107.0	99.0	97.5	106.0	67.0
7	9.7	23.0	70.5	100.0	94.0	91.0	99.0	59.0
8	8.0	19.0	63.5	95.0	88.0	87.0	94.5	49.0
9	6.4	16.0	56.5	90.0	83.0	82.0	88.5	43.0
10	4.9	11.5	51.0	85.0	78.5	78.0	83.0	35.0
11	3.9	9.0	45.0	80.0	74.5	74.5	78.5	32.0
12	2.5	6.2	41.0	77.0	72.0	71.5	75.0	25.0
13	2.2		39.5	76.0	71.0	70.5	73.5-	24.0
14	1.1		34.5	73.0	69.0	67.5	71.0	20.0

Table No. 7.

Calibration of Mud Gauges.

Temperature of Room-----73.0 F. February 6,,1914.

Ref. No.	457 lb. per sq. in.	709 ft.	130	128	129	60	127	56
1	19.2	25.5	104.0	123.0	116.0	90.0	113.0	123.0
2	17.3	41.0	98.0	119.0	114.0	86.0	111.0	121.0
3	15.4	36.5	92.0	114.0	111.0	83.0	109.0	119.0
4	13.5	32.0	85.0	109.0	107.0	76.0	105.0	114.0
5	11.5	27.5	76.0	102.0	102.0	69.0	100.0	109.0
6	9.4	23.0	68.0	97.0	96.0	60.0	95.0	103.0
7	7.9	19.0	62.0	92.0	91.0	50.0	89.0	97.0
8	7.1	17.0	59.0	89.0	86.0	43.0	85.0	93.0
9	6.0	15.0	54.0	86.0	84.0	39.0	83.0	89.0
10	5.0	12.0	49.0	81.0	81.0	34.0	80.0	86.0
11	4.0	10.0	45.0	79.0	77.0	28.0	77.0	81.0
12	3.0	8.0	42.0	76.0	75.0	23.0	74.0	78.0
13	2.2		38.0	74.0	72.0	18.0	71.0	76.0
14	1.2		33.0	71.0	71.0	14.0	69.0	72.0



Calibration Curve
of the
Bourdon Gauge
with the
Crosby Gauge Tester

Plate VI

Calibration Curve
for
Pressure Gauges

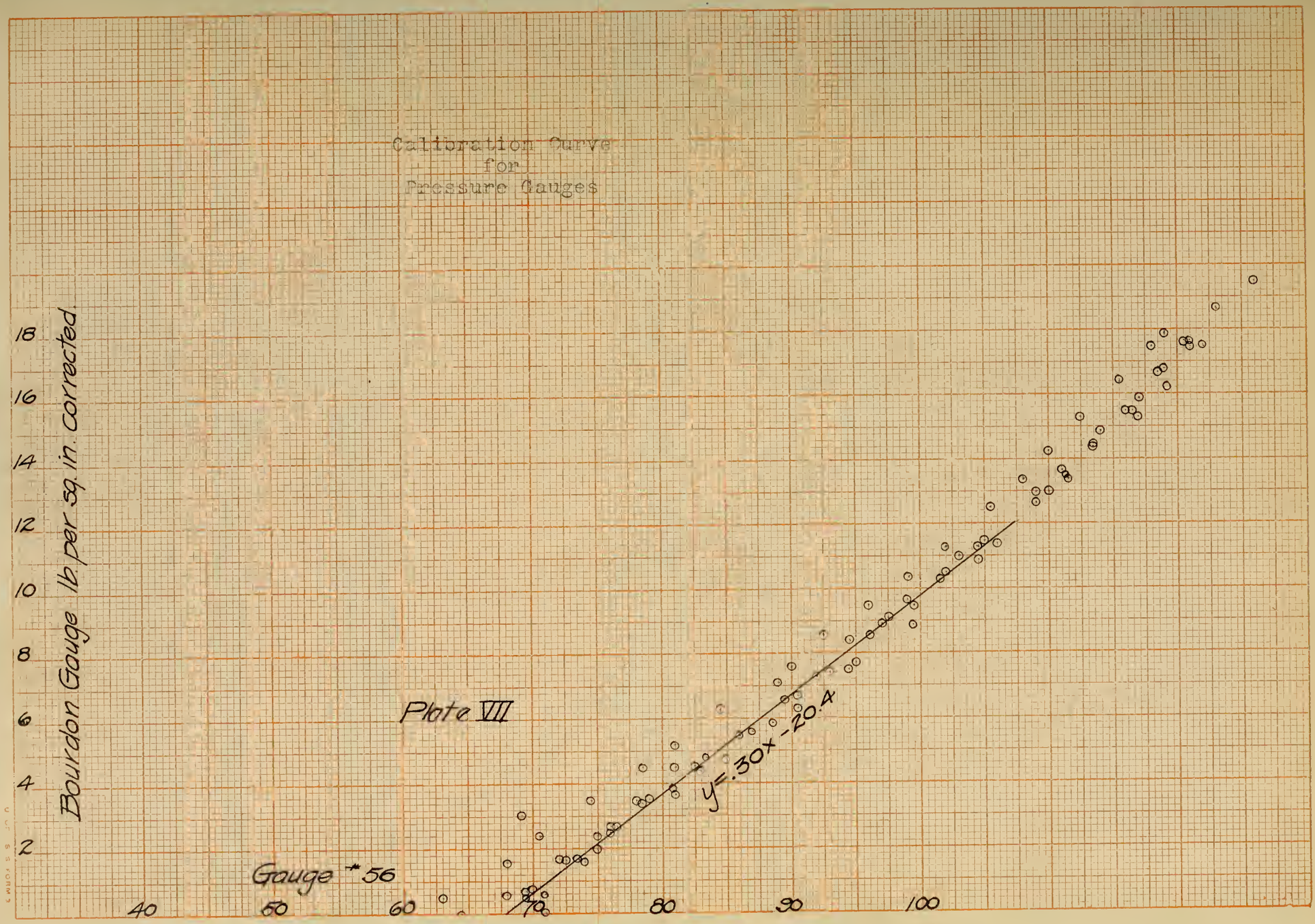
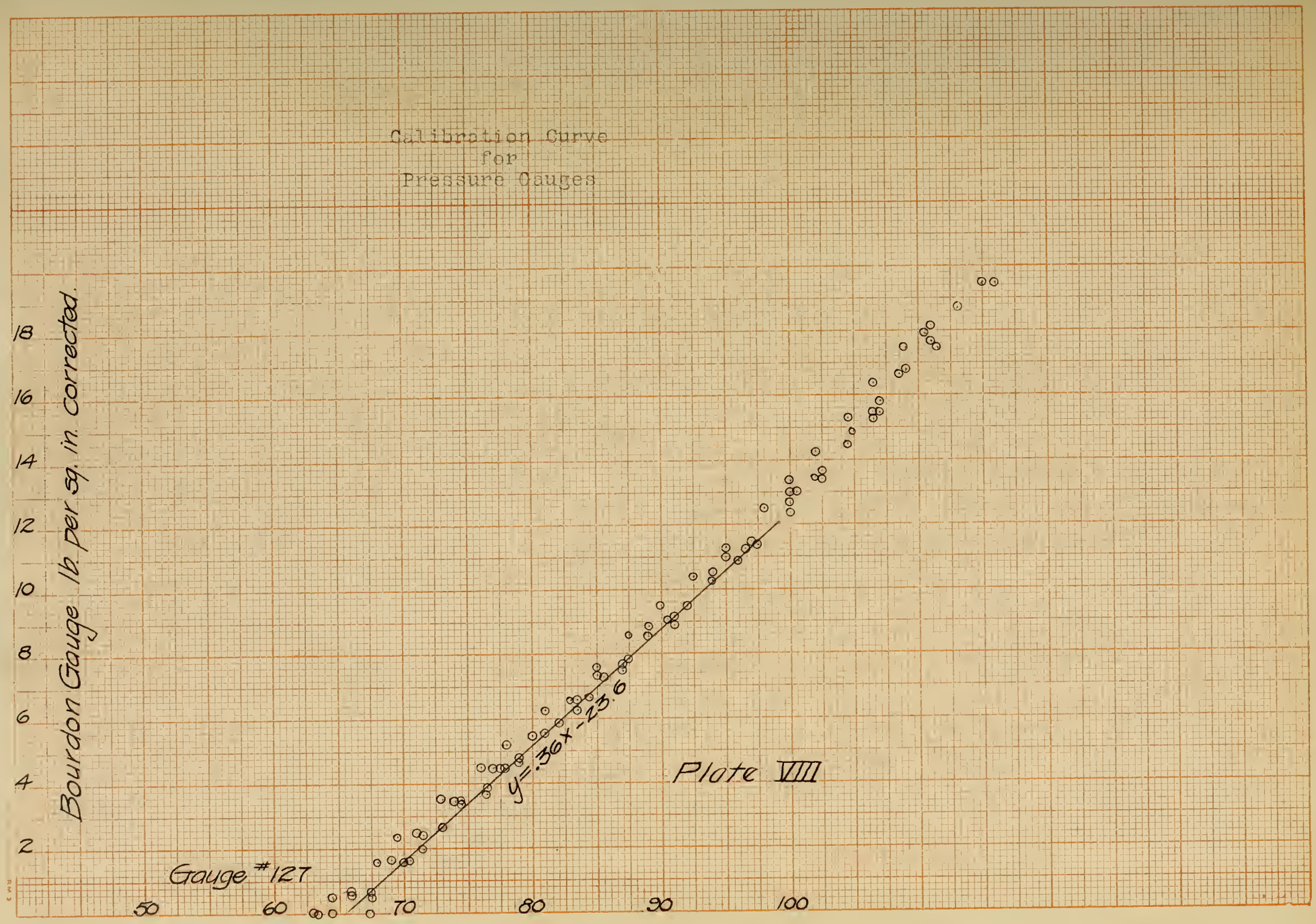
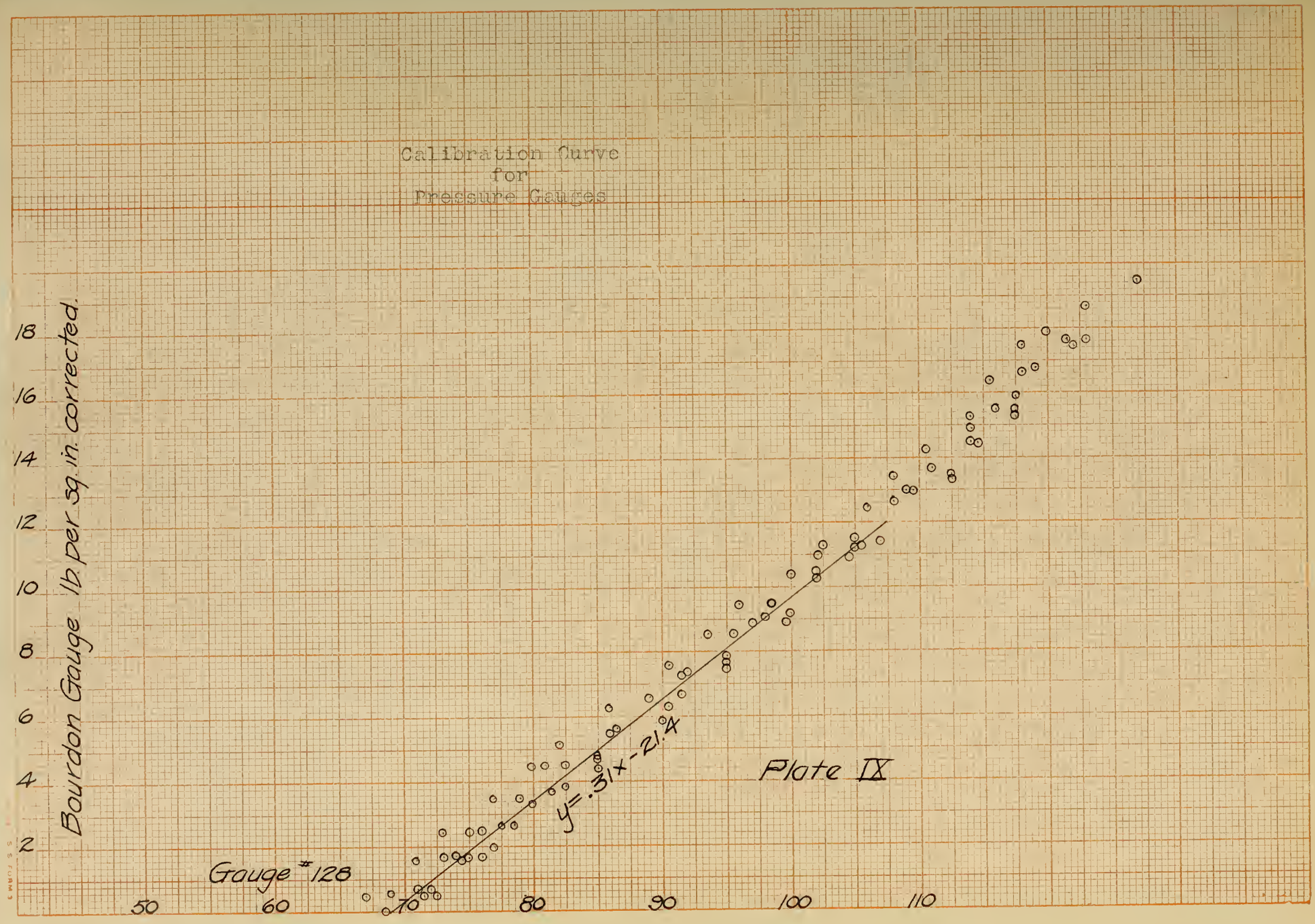
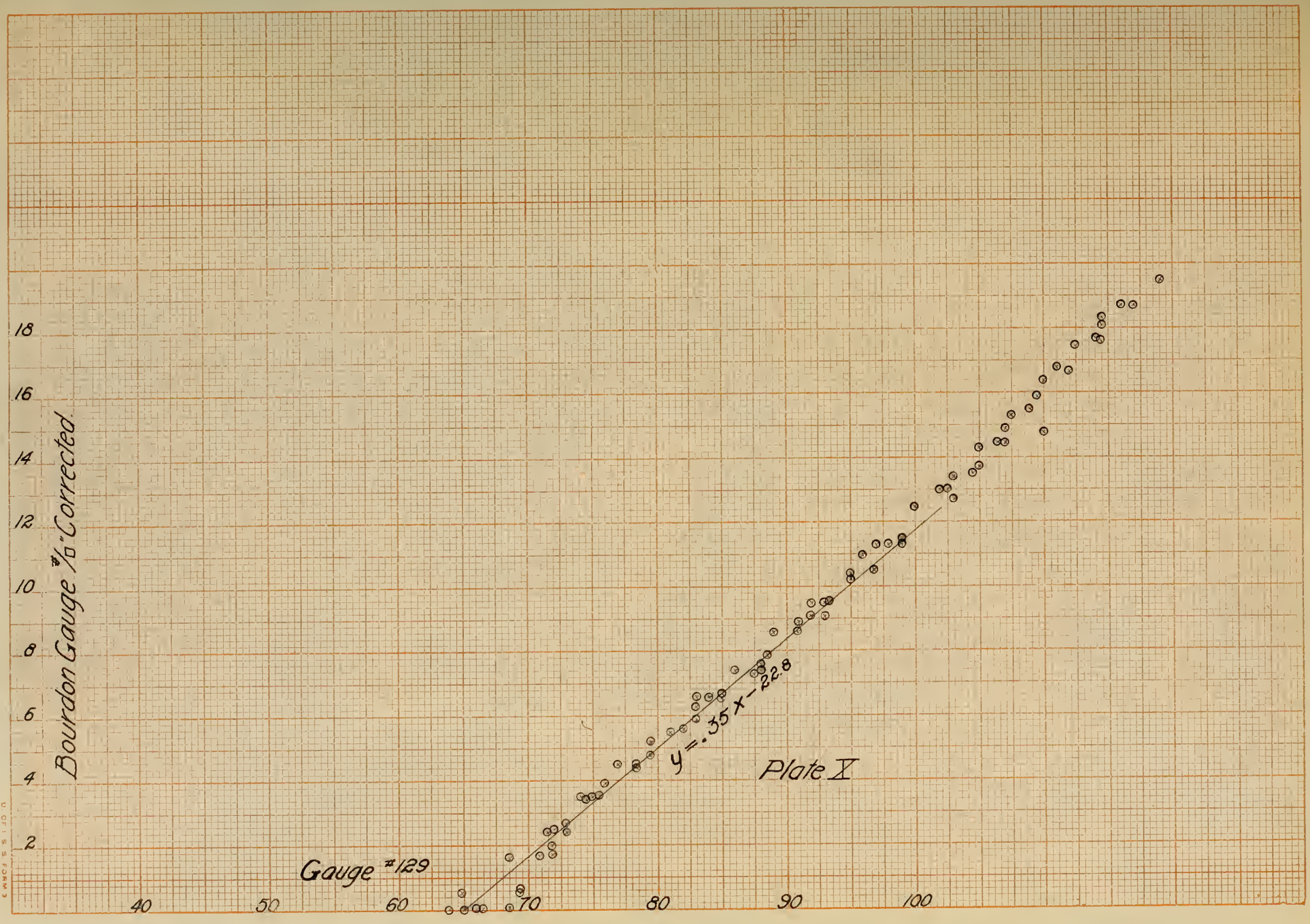


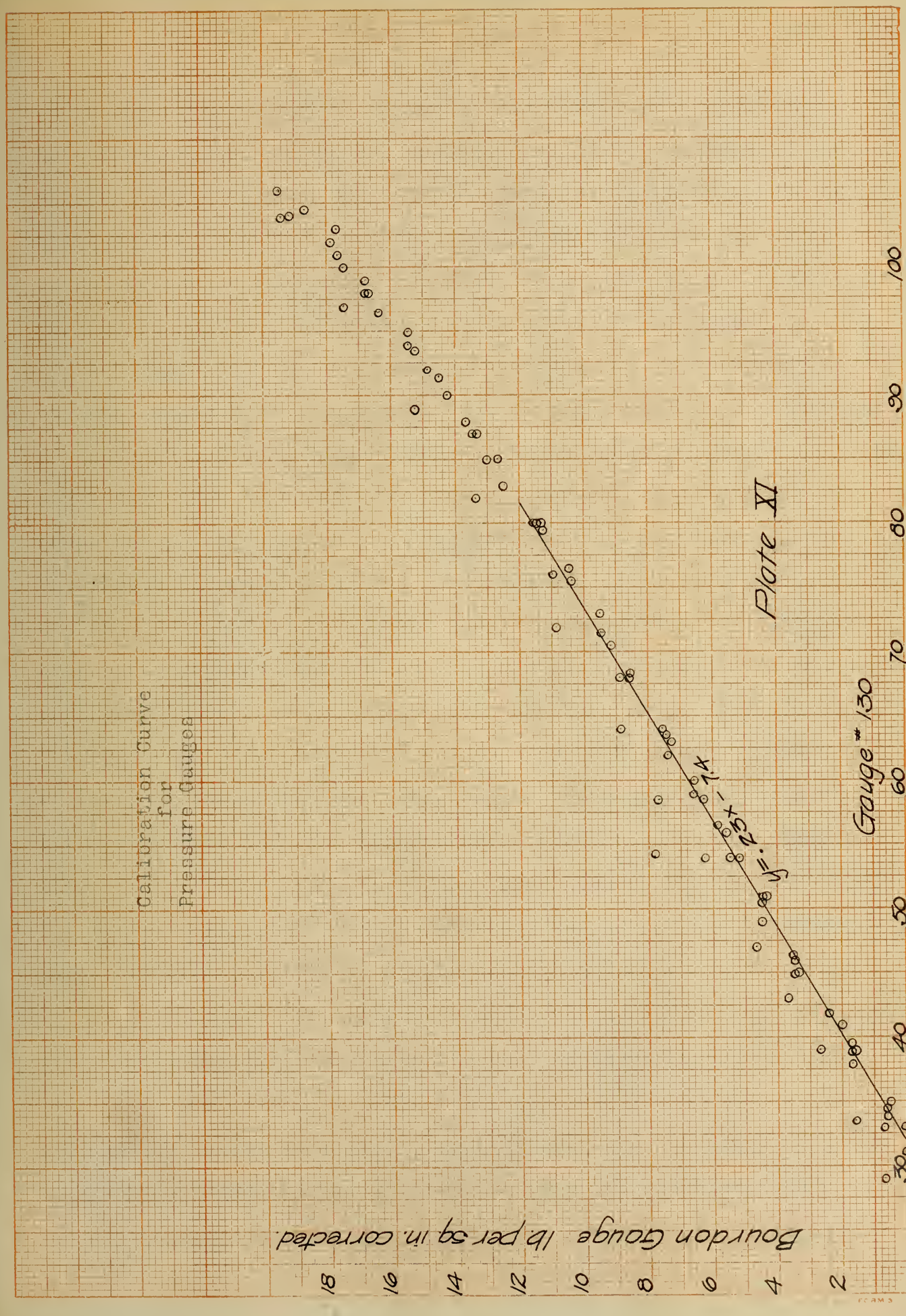
Plate VII


Calibration Curve
for
Pressure Gauges
Bourdon Gauge lb per sq. in. corrected.
2
4
6
8
10
12
14
16
18
50
60
70
80
90
100
y=.36x-23.6
Gauge #127
Plate VIII

Calibration Curve
for
Pressure Gauges




Bourdon Gauge #10 Corrected
Gauge #129
y = .35x - 22.8
Plate X
18
16
14
12
10
8
6
4
2
40
50
60
70
80
90
100

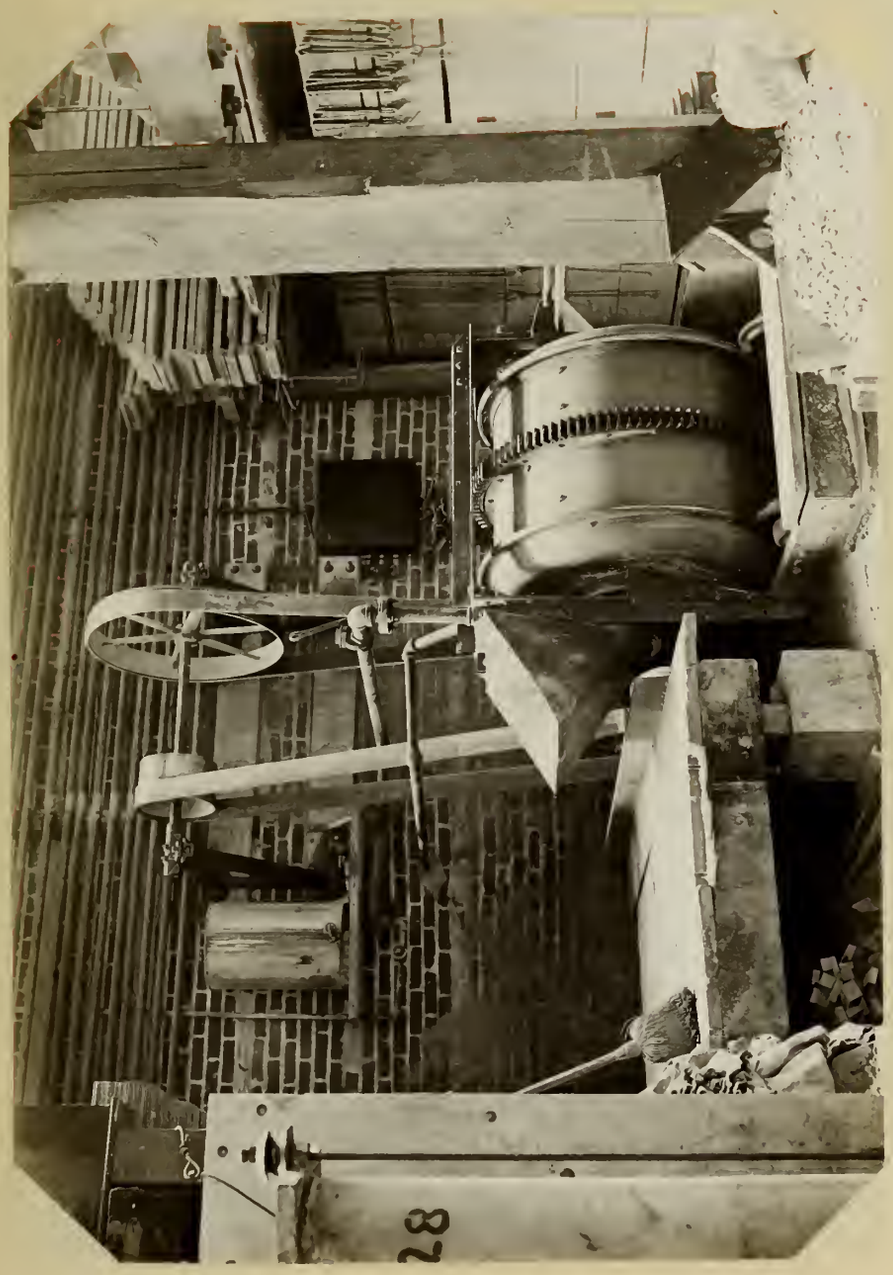

Calibration Curve
for
Pressure Gauges
Plate XI
Gauge # 130
y = .25x - 1.1
Bourdon Gauge lb per sq in. corrected
2
4
6
8
10
12
14
16
18
30
40
50
60
70
80
90
100

stand pipe. Plate V shows the calibration apparatus complete. Pet cocks on the calibration casting insured the removal of all air from this cylinder and especial care was taken to secure water-tight joints in all the connections. After the gauges had been tested to see if they would stand up under pressure for twenty-four hours, several calibrations were made. The Bourdon gauge was the standard gauge for all calibrations and was quite sensitive to small changes of pressure. It was in turn carefully calibrated by means of a Crosby Gauge Tester by which known pressures in pounds per square inch were applied. A nearly constant correction was found for all readings of the Bourdon gauge (see Table I,page 14). The corrected readings of the latter were plotted as ordinates against the readings of the mud gauges as abscissae in making the calibration curves.(see Tables 2 to 7 incl.,pages 15 to 20 incl.). Several calibrations were made early in the winter, while the last six were made just before the gauges were used in the column tests. It was noticeable that the later calibrations gave considerably lower pressures than the earlier ones, partly due to the change in flexibility of the gauge diaphragms under continued use, and partly due to the change in the temperature of the air of the calibration room. The only temperature factor considered was that of the air in the rooms where the tests were made. The temperature of the water used in calibrating the gauges and that of the concrete used for the tests were very nearly the same. However, the effect of the temperature of the material in contact with the diaphragms was practically negligible,because of the very low coefficient of thermal conductivity of the grease which covered the diaphragms.

Hence in drawing the calibration curves the calibrations which were made on the days of the column tests were given the more weight. Calibration curves were not drawn for pressures above 12 pounds per square inch, since none of the pressures from the tests ran above this amount. The calibration apparatus, with the gauges in place, is shown in Fig. 4. The pipe at the right of the picture leads to the stand pipe.

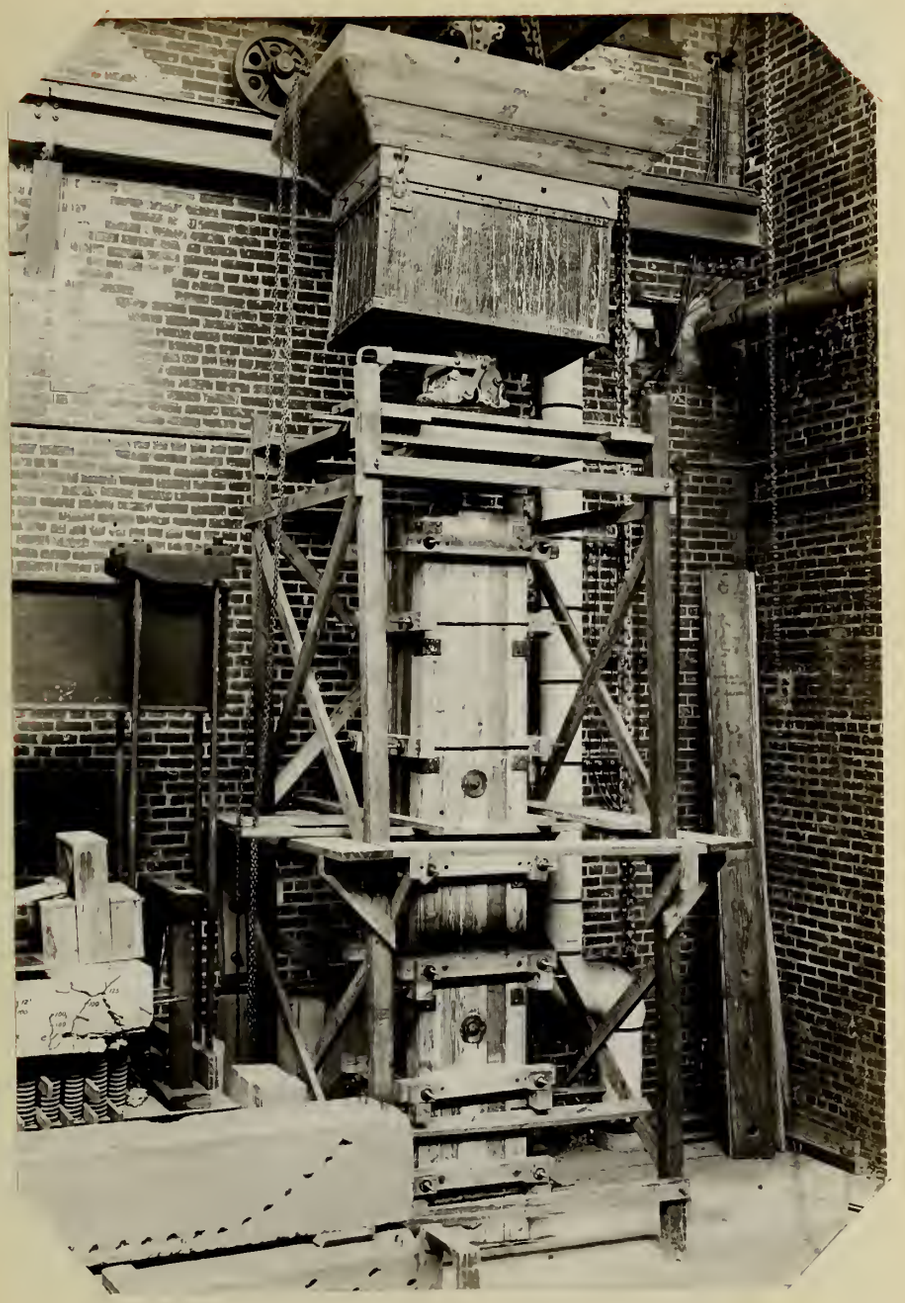
2. Column Tests.-

(a) Mixing.- Six column tests were made on February 5,6, and 7, 1914, on the twelve and twenty inch square column forms. The tests on the sixteen and twenty-four inch square columns were not made at this time. The concrete was mixed in a one-third cubic yard, motor-driven batch mixer shown in Fig. 4. For the first four columns the concrete was mixed in two batches, the first being dumped on the floor until the second was mixed. The amounts of all materials used are given in tables 15 to 21. The material was taken in wheel barrows from the mixing floor, up an inclined runway, to a height of about five feet above the floor. The bucket was then raised by the use of the crane and moved into position directly over the funnel.



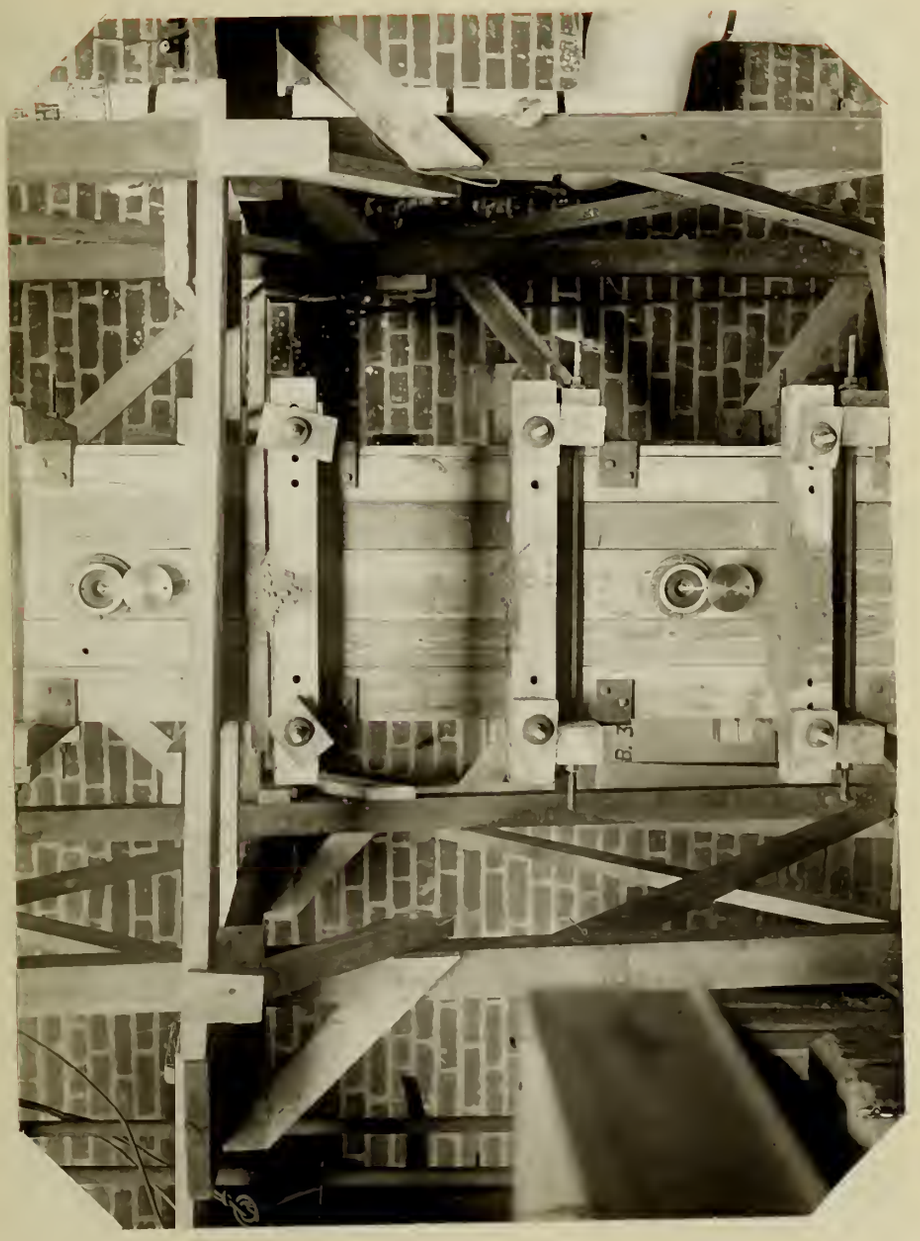
View of Batch Mixer

Figure No.4.



View of Apparatus Before Pouring

Figure No.5.



View Showing Gauges in Place

Figure No.6.

(b)- Pouring. The columns were poured very rapidly, the time varying from three to nine minutes, giving a rate of from one and one-third to four cubic feet per minute. In performing the tests, five men read gauges, one kept time and read heights of concrete, and two did the pouring. Simultaneous readings were taken at fifteen second intervals determined by the use of a whistle signal. After the pouring was completed, readings were continued at longer intervals for about an hour, for the purpose of noting the effect of the hardening of the concrete on the pressure exerted.

3. Tests of Materials.-

(a) Cement.- The cement used, Universal Portland, was of the standard quality employed for general construction purposes. The proportioning of this cement was done entirely by the weight method.

A fineness test was made of this cement, and it conformed to the standard specifications of the American Society of Testing Materials. Data for this test is given on Page 32 .

A plasticity test giving 22.5 percent of water was also made; see data on page 33 . Two neat cement pats were quite firm and solid after a period of twenty-eight days in water.

Six neat cement and six 1:3 cement mortar briquettes were made and tested in order to obtain the tensile strength of the cement. Standard briquette forms were used. Results and curves of these tests are given on page 34 and Plate XII respectively.

As far as these tests showed, the cement conformed in every respect to the standard specifications previously mentioned.

Table No. 8.

Fineness Test of Universal Portland Cement.

March 26, 1914.

Amount of Cement Used----------	1000.0 units.
Amount left on 200 mesh sieve----------	227.5 units.
Amount left on 100 mesh sieve----------	40.0 units.
Checked weight----------	997.0 units.

	Experiment.	Standard.
Amount retained on 200 mesh	22.75%	25.00%
Amount retained on 100 mesh	4.00%	8.25%

Table No. 9.

Plasticity of Universal Portland Cement.

March 20, 1916.

500 grams of Cement Used.

Dried.

No of Test.	Amount of Water. c.c.	Amount of Water. Temp.	Penetration. cm.
1	22.0	115.0	1.0
2	22.5	112.5	9.0
3	23.0	115.0	11.0
4	22.5	112.5	9.0

Temperature of Air------ - 22.5 C.

Temperature of Water---- 20.0 C.

Table No. 10.

Strength of Neat Mortar and 1-3 Cement Mortar Briquettes.

Universal Portland Cement Mfg.

7 Day Test. April 1, 1914.

Data.

Reference Number.	Neat Cement.		1-3 Cement Mortar.	
	Weight. grams	Strength. lb per sq in	Weight. grams	Strength. lb per sq in
1	146.7	610.	145.4	340.
2	146.9	700.	146.2	410.
3	147.2	630.	146.8	380.

9 Day Test. April 3, 1914.

1	145.8	670.	144.6	400.
2	146.5	730.	145.0	440.
3	146.0	680.	144.8	420.

Note: Percent water used in Neat Cement Briquettes 24.5
Percent water used in 1-3 Mortar Briquettes 12.5

Curves Showing
Strength of Briquettes.
Period 1-28 days.

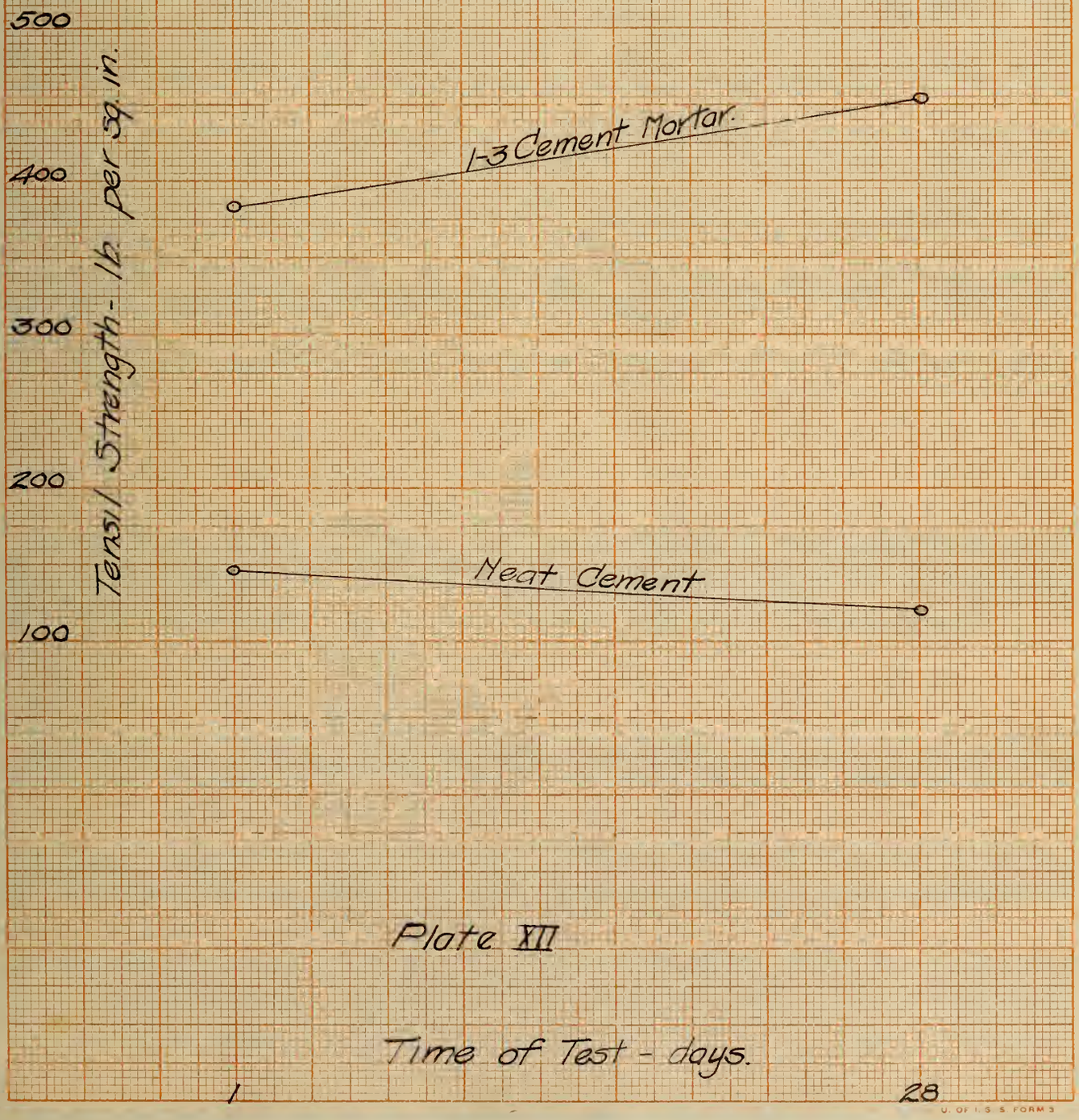


Plate XII

Table No. 11.

Test of Sand.

April 28, 1914.

DATA.

No. of sieve.	grams retained.	percent retained.
5	112.7	11.27
8	127.7	12.77
10	65.5	6.54
16	198.5	19.85
20	43.7	4.37
30	136.2	13.62
40	154.7	15.47
60	98.5	9.85
74	18.2	1.82
100	16.2	1.62
150	5.8	0.58
200	1.9	0.19
Material in suspension	12.5	1.25
Pan	5.0	0.50
	998.0	99.80

Table No. 12.

Test of Stone.

April 28, 1914.

Total weight of stone used----------	2500.0 grams	
Retained on 1" sieve----------	98.1 grams	3.92%
Retained on ½". sieve----------	1271.3 grams	50.80%
Retained on ¼" sieve----------	1035.5 grams	41.40%
On pan----------	89.1 grams	3.96%
Checked weight----------	2494.0 grams	

Table No. 13.

Data for Sieve Analysis Curves.

Sand.

No. of sieve.	Dia. of sieve openings. inches	Amount retained. grams	Amount coarser than given dia. grams	Total sand passing of given diameter. grams	percent
	0.20	0.0	0.0	1000.0	100.0
5	0.160	112.7	112.7	887.3	88.7
8	0.093	127.7	240.4	759.6	76.0
10	0.073	65.5	305.9	694.1	69.4
16	0.042	198.5	504.4	495.6	49.6
20	0.034	43.7	548.1	451.9	45.2
30	0.022	136.3	684.3	315.7	31.6
40	0.015	154.7	839.0	161.0	16.1
60	0.0090	98.5	937.5	62.5	6.2
74	0.0078	18.2	955.7	44.3	4.4
100	0.0045	16.2	971.9	28.1	2.8
150	0.0033	5.8	977.7	22.3	2.3
200	0.0027	1.9	979.6	20.4	2.0
Suspension		12.5	992.1	7.9	0.8
Pan		5.0	997.2	2.8	0.3

Stone.

0.0	0.0	0.0	0.0	2500.0	100.0
1	1.0	98.1	98.1	2401.9	96.1
5	5.0	1271.3	1369.4	1130.6	45.2
25	25.0	1035.5	2404.9	95.1	38.0
Pan		89.1	2494.0	6.0	2.4

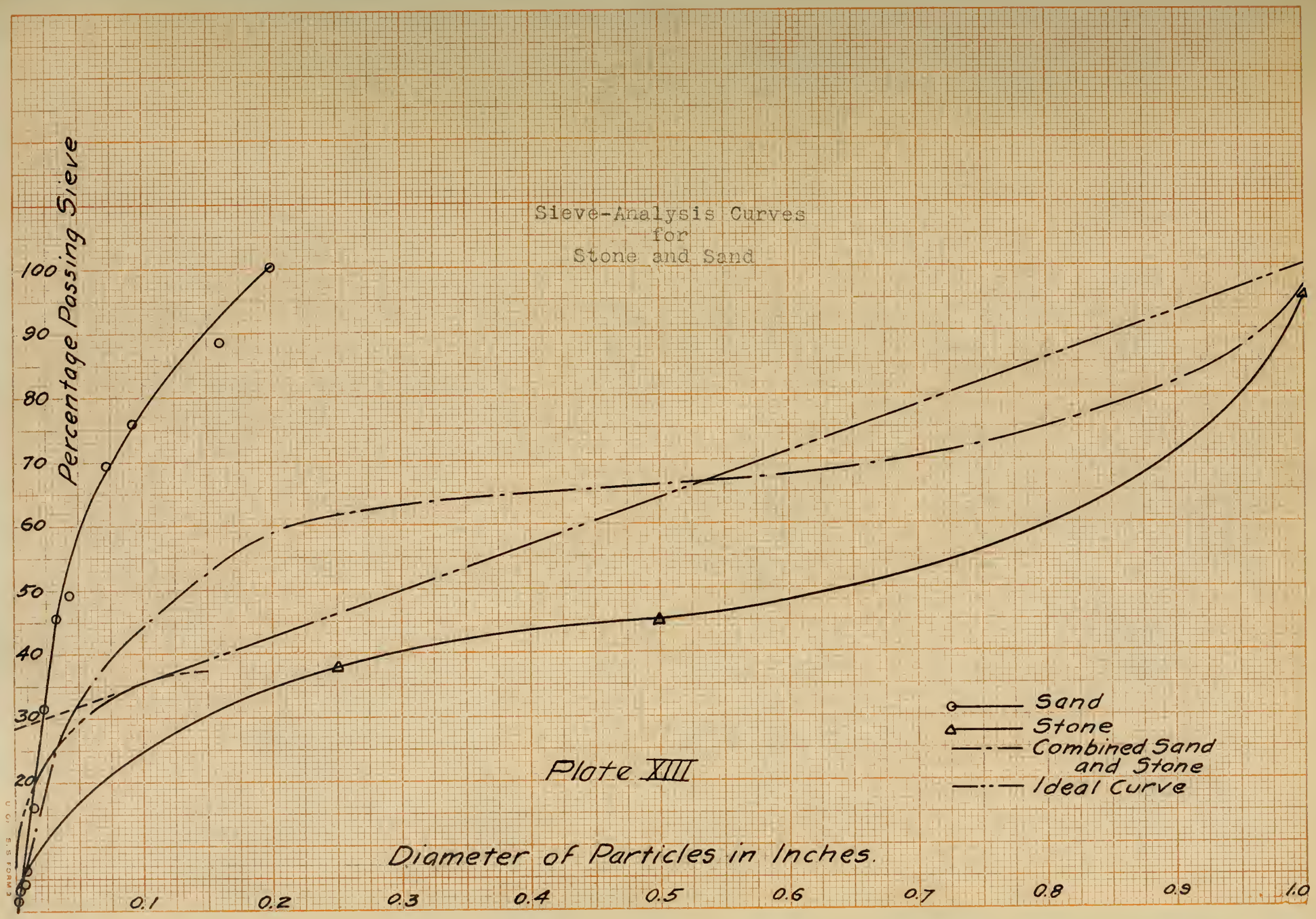

Sieve-Analysis Curves
for
Stone and Sand
Percentage Passing Sieve
100
90
80
70
60
50
40
30
20
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Diameter of Particles in Inches.
Sand
Stone
Combined Sand and Stone
Ideal Curve
Plate XIII

Table No. 14.

Test of 6" Concrete Cubes.

March 6, 1914.

Column No.	Cube No.	Ultimate Strength lb.	Unit Strength lb. per sq. in.	Weight lb.	Remarks
4	1	39250.0	1090.0		
4	2	39890.0	1110.0		
4	3	39180.0	1090.0		
		March 7, 1914.			
5	1	45630.0	1296.0	18.50	
5	2	44740.0	1243.0	18.75	Cubes were
5	3	33550.0	932.0	18.70	weighed after
6	1	37650.0	1046.0	18.25	plastering.
6	2	41670.0	1159.0	18.25	
6	3	39720.0	1103.0	18.20	

(b) Sand and Stone.- The suspension test made of the sand indicated that it was quite clean; as only 12.5 out of 1000 grams were washed out. A sieve test was made using sieves from a 5 to 200 meshes per inch, and from the data obtained by this test, a sieve-analysis curve was drawn; see Plate XIII.

Practically the same kind of tests was made on the crushed stone that was used, and a sieve analysis curve is also given on Plate XIII. These curves show that a greater percentage of sand would have made a denser mixture.

(c) Test of Six-Inch Concrete Cubes.- Three six-inch concrete cubes were made from the concrete used in each test of the 20 inch square column. These cubes were tested for crushing strength, and gave values ranging from 950 to 1300 pounds per square inch; see page 40 . These values check very closely with similar tests made at this and other universities.

IV. RESULTS AND CONCLUSIONS.

1. Effect of Impact.- Since the rate of pouring of the concrete columns was quite rapid and the material dropped thru a maximum distance of about thirteen feet, it might be assumed that the impact would materially increase the pressure on the gauges. However a little consideration shows that this effect is not large. The total pressure due to impact for an interval of time is equal to the falling mass multiplied by the change of velocity during the interval. Expressed mathematically, the pressure $P = M \frac{\Delta v}{\Delta t}$, and the instantaneous pressure is equal to $M \frac{dv}{dt}$. The maximum rate of pouring was 48 cubic feet in $5\frac{1}{2}$ minutes or 0.145 cubic feet per second, and the average velocity of material falling was 27.8

TABLE NO. 15.

COLUMN TEST NO. 1.

12 Inch Square Column. Thursday, Feb.5,1914.

Reading No.	Time Interval sec.	Head Reading Ft.	Gauge Readings. No.130	No.128	No.129	No.127	No.56
1	30	0.0	27.0	65.0	65.0	64.0	65.0
2	"	4.4	45.0	75.0	67.0	64.0	65.0
3	"	5.0	54.0	83.0	74.0	67.0	65.0
4	"	7.7	54.0	83.0	75.5	69.0	65.0
5	"	8.5	48.0	81.0	74.0	70.0	
6	"	8.5	47.0	81.0	76.0	72.0	
7	"	9.0	46.5	81.5	75.0	71.0	
8	"	9.0	45.0	79.0	74.0	70.0	
9	"	10.0	44.0	79.0	73.5	70.0	
10	"	10.0	43.0	79.0	73.0	70.0	
11	"	11.0	42.5	77.5,	72.5	70.0	
12	"	11.6	41.5	77.5	72.5	69.5	
13	"	12.0	41.5	76.0	71.5	69.5	
14	"	"	41.5	76.0	71.5	69.0	72.0
15	"	"	40.5	76.0	72.0	69.0	72.0
16	"	"	40.5	74.5	72.0	69.0	72.0
17	60	"	39.5	74.5	72.0	68.5	72.0
18	"	"	39.0	74.5	72.0	68.5	72.0
19	"	"	38.0	74.5	72.0	68.0	72.0
20	"	"	38.0	74.5	72.0	68.0	71.5
21	"	"	37.5	74.5	72.0	68.0	71.5
22	"	"	37.0	73.0	70.5	68.0	71.5
23	"	"	36.5	73.0	70.5	68.0	71.5
24	"	"	36.0	73.0	70.5	68.0	71.5
25	"	"	36.0	73.0	70.5	68.0	71.5
26	"	"	35.5	73.0	70.5	67.8	71.5
27	"	"	35.0	72.0	70.5	67.8	71.5
28	"	"	35.0	72.0	70.5	67.8	71.5
29	"	"	34.5	72.0	70.5	67.8	71.5
30	"	"	34.0	72.0	70.5	67.8	71.5
31	"	"	34.0	71.0	70.5	67.8	71.5
32	"	"	33.0	71.0	70.5	67.8	71.5
33	"	"	33.0	71.0	70.5	67.8	71.5
34	"	"	33.0	71.0	70.5	67.8	71.5
35	"	"	33.0	71.0	70.5	67.8	71.5
36	"	"	33.0	71.0	70.5	67.7	71.5
37	"	"	33.0	71.0	70.5	67.7	71.5
38	"	"	33.0	71.0	70.5	67.7	71.5

Time of mixing, per batch-3 1/2 minutes. Room temperature 78 deg.F.
Time of pouring - --------6 minutes.
Total time of test,--- --34 minutes.
Weight of materials,in pounds--------

Batch	Stone	Sand	Cement	Water	Total
1	480	290	141	78	
2	483	285	141	90	
	963	575	282	168	1988

TABLE NO. 16.

COLUMN TEST NO. 2.

12 Inch Square Column. Thursday, Feb. 5, 1914.

Reading No.	Time Interval sec.	Head Reading ft.	Gauge Readings No.130	No.128	No.129	No.127	No.56
1	15	0.0	26.5	65.0	65.0	64.3	
2	"		43.0	70.0	65.0	64.4	
3	"		45.0	75.0	68.0	64.4	
4	"		47.5	77.0	69.5	64.5	
5	"	4.0	52.5	81.0	72.5	65.8	
6	"		57.5	85.0	76.5	69.5	
7	"		60.5	87.0	78.5	71.5	
8	"		63.5	90.0	82.0	75.2	
9	"	8.0	64.5	91.0	85.5	78.2	
10	"		67.0	93.0	85.5	80.0	80.0
11	"		66.0	95.0	85.5	79.0	80.0
12	"		63.5	93.0	85.5	78.7	
13	"	12.0	62.5	93.0	84.5	78.4	
14	"	"	61.0	91.0	84.0	78.0	
15	"	"	59.5	91.0	83.0	77.5	
16	"	"	58.5	89.5	82.5	77.1	78.5
17	"	"	57.5	89.5	82.5	76.7	78.5
18	"	"	56.0	88.5	81.5	76.4	78.5
19	"	"	55.0	88.5	81.0	76.1	78.5
20	"	"	54.5	88.5	80.5	75.9	77.5
21	"	"	54.0	87.0	80.0	75.5	77.5
22	"	"	54.0	87.0	79.5	75.3	77.5
23	"	"	52.5	86.0	79.5	75.1	77.5
24	"	"	51.5	86.0	79.0	74.9	77.5
25	"	"	51.0	85.5	79.0	74.7	76.0
26	"	"	50.5	85.5	78.5	74.6	76.0
27	"	"	50.0	85.5	78.5	74.4	76.0
28	"	"	49.5	85.5	78.5	74.2	76.0
29	"	"	48.5	84.0	78.5	74.2	76.0
30	"	"	48.0	84.0	78.5	73.6	76.0
31	"	"	47.5	84.0	78.5	73.5	76.0
32	"	"	47.5	84.0	78.5	73.5	76.0
33	60	"	46.0	82.5	76.5	73.0	76.0
34	"	"	44.5	81.5	75.5	72.5	74.5
35	"	"	44.0	81.0	75.0	72.1	74.5
36	"	"	43.0	80.0	74.0	71.9	74.5
37	"	"	42.5	80.0	74.0	71.3	74.5
38	"	"	42.0	78.5	74.0	71.1	73.0
39	"	"	41.5	78.5	73.5	70.5	72.8
40	"	"	41.0	78.5	73.5	70.5	72.8
41	"	"	40.5	78.5	73.0	70.3	72.8
42	"	"	40.5	78.5	73.0	70.3	72.5
43	"	"	40.0	78.5	73.0	70.0	72.5
44	"	"	39.5	78.5	73.0	69.8	72.5
45	"	"	39.0	76.5	73.0	69.8	71.0
46	"	"	38.5	76.5	73.0	69.6	71.0

COLUMN TEST NO. 2.-Continued.

Reading No.	Time Interval sec.	Head Reading ft.	Gauge Readings No.130	No.128	No.129	No.127	No.56
47	60	12.0	38.5	76.5	73.0	69.6	71.0
48	"	"	38.0	76.5	73.0	69.6	71.0
49	"	"	38.0	76.5	73.0	69.6	71.0
50	"	"	38.0	76.5	73.0	69.6	71.0
51	"	"	37.5	76.5	73.0	69.4	71.0
52	"	"	37.5	75.0	73.0	69.4	71.0
53	"	"	37.0	75.0	73.0	69.4	71.0
54	"	"	36.5	75.0	73.0	69.0	71.0
55	"	"	36.0	75.0	73.0	69.0	71.0
56	"	"	36.0	75.0	73.0	69.0	71.0
57	"	"	36.0	75.0	73.0	69.0	71.0
58	"	"	35.5	75.0	73.0	68.7	71.0
59	"	"	35.5	74.0	73.0	68.7	71.0
60	"	"	35.0	74.0	72.0	68.7	71.0
61	300	"	34.5	74.0	72.0	68.0	70.0
62	"	"	34.0	74.0	72.0	67.7	70.0
63	"	"	33.0	72.0	71.5	67.7	70.0
64	"	"	32.5	72.0	71.5	67.3	70.0
65	"	"	32.0	72.0	71.5	67.3	70.0
Height of gauges from base			6.0"	21.5"	42.5"	67.0"	91.0"

Temperature of room- 75 degrees F.
Time of pouring------- -3 minutes.
Total time of test-----61 minutes.
Proportions of concrete---- 1:2:4.
Weight of materials,in pounds----

Batch	Stone	Sand	Cement	Water	Total
1	502	294	141	78	
2	496	295	141	84	
	998	589	282	162	2031

TABLE NO. 17.

COLUMN TEST NO. 3.

12 Inch Square Column. Friday, Feb. 6, 1914.

Reading No.	Time Interval sec.	Head Reading Ft.	Gauge Readings No.128	No.130	No.129	No.127	No.56
1	15	0.0	64.0	26.0	64.0	64.0	65.0
2	"		68.5	26.0	64.0	64.0	65.0
3	"		71.0	27.5	64.0	64.0	65.0
4	"		71.5	29.5	64.0	64.0	65.0
5	"		74.0	33.0	64.0	64.0	65.0
6	"		75.3	34.0	64.0	64.0	65.0
7	"	4.0	77.0	36.5	64.0	64.0	65.0
8	"		78.3	38.5	65.5	64.0	65.0
9	"		79.0	40.0	67.0	64.0	65.0
10	"		80.0	41.0	67.5	64.0	65.0
11	"		80.7	42.0	68.5	64.0	65.0
12	"		81.5	44.0	69.0	64.0	65.0
13	"		82.3	45.0	70.0	64.0	65.0
14	"		83.0	46.0	71.0	64.4	65.0
15	"		83.5	47.5	71.5	65.0	65.0
16	"		83.5	47.5	72.0	66.0	65.0
17	"		84.0	48.0	73.0	67.0	65.0
18	"		86.0	52.0	75.0	69.0	65.0
19	"		86.0	53.0	75.5	69.0	65.0
20	"	8.0	86.0	53.0	76.0	70.0	65.0
21	"		86.0	53.0	76.0	70.5	65.0
22	"		86.0	53.0	76.5	71.0	67.0
23	"		86.0	53.0	76.5	71.0	68.0
24	"		86.0	52.5	76.5	71.5	69.0
25	"		86.0	52.5	76.5	71.5	69.0
26	"		85.8	52.5	76.5	71.5	69.0
27	"		85.8	52.5	76.5	71.5	69.0
28	"		85.8	52.0	76.5	71.5	69.0
29	"		85.8	52.0	76.5	71.5	69.0
30	"		85.8	52.0	76.5	71.5	69.0
31	"		85.8	52.0	76.5	71.5	70.0
32	"		85.8	52.0	76.5	71.5	70.0
33	"		85.8	52.0	76.5	71.5	70.0
34	"		85.8	51.0	75.5	71.5	70.0
35	"		85.8	51.0	75.5	71.5	70.0
36	"		85.8	51.0	75.5	71.5	70.0
37	"		85.8	51.0	75.5	71.5	70.0
38	"		85.8	51.0	75.5	71.5	70.0
39	"	12.0	85.8	51.0	75.5	71.5	71.0
40	"	"	85.8	51.0	75.5	71.5	71.0
41	"	"	84.3	51.0	75.5	71.5	71.0
42	"	"	84.3	51.0	75.5	71.5	71.0
43	"	"	84.3	51.0	75.5	71.5	70.5
44	"		84.3	51.0	75.0	71.5	70.5
45	"	"	84.3	51.0	75.0	71.5	70.5

COLUMN TEST NO. 3.-Continued.

Reading No.	Time Interval sec.	Head Reading ft.	Gauge Readings No.128	No.130	No.129	No.127	No.56
46	15	12.0	84.3	51.0	75.0	72.0	70.5
47	"	"	84.3	51.0	75.0	72.0	70.5
48	"	"	84.3	51.0	75.0	71.5	70.5
49	"	"	83.0	51.0	74.5	71.5	70.5
50	"	"	83.0	51.0	74.5	71.5	70.5
51	60	"	83.0	51.0	74.5	71.5	70.5
52	"	"	83.0	51.0	74.5	71.5	70.5
53	"	"	81.5	51.0	74.0	71.5	70.5
54	"	"	81.5	51.0	74.0	71.5	70.7
55	"	"	81.5	51.0	74.0	71.5	70.7
56	"	"	80.5	51.0	74.0	71.5	70.7
57	"	"	80.5	51.0	74.0	71.5	70.7
58	"	"	80.5	51.0	74.0	71.5	70.5
59	"	"	80.5	51.0	73.0	71.5	70.5
60	"	"	79.0	51.0	73.0	71.5	70.5
61	300	"	79.0	46.5	73.0	71.0	70.5
62	"	"	77.0	45.0	72.5	70.5	70.5
63	"	"	76.5	45.0	72.0	70.5	70.5
64	"	"	75.5	43.5	72.0	70.5	70.5
65	"	"	74.5	42.0	72.0	70.0	70.0
66	"	"	74.5	40.0	72.0	70.0	70.0
67	"	"	72.5	39.0	72.0	70.0	70.0
68	"	"	72.5	38.0	70.0	70.0	70.0
Height of gauges from base-			6.0"	21.5"	42.5"	67.0"	91.0"

Temperature of room- 72 degrees F.
Time of mixing concrete, per batch-3 1/2 minutes.
Total time of mixing concrete----------18 minutes.
Time of pouring---------- ---------- 9 minutes.
Total tome of observations---- - ------62 minutes.

Weight of materials,in pounds------

Batch	Stone	Sand	Cement	Water	Total
1	492	295	141	83	
2	491	290	141	89	
	983	585	282	172	2022

Table No. 18.

COLUMN TEST NO. 4.

20 Inch Square Column. Friday, Feb.6, 1914.

Reading No.	Time Interval sec.	Head Reading ft.	Gauge Readings No.130	No.128	No.129	No.127
1	15	0.0	26.5	67.0		65.0
2	"	0.8	27.5	67.0		65.0
3	"		38.5	72.0		65.0
4	"	3.1	39.0	72.0	64.5	65.0
5	"	3.6	39.5	72.0	65.0	65.0
6	"	4.1	41.0	72.5	65.0	65.0
7	"	4.3	42.5	74.0	65.0	65.0
8	"	4.4	43.0	75.0	66.0	65.0
9	"	4.9	46.0	77.5	68.5	65.0
10	"	5.1	47.0	78.0	68.5	65.0
11	"	5.5	48.0	79.5	70.5	65.0
12	"		48.5	80.5	71.5	66.0
13	"		51.0	83.0	73.0	67.5
14	"	5.7	51.5	83.0	73.5	68.0
15	"	5.8	51.5	83.0	73.5	69.0
16	"	5.9	51.5	83.0	73.5	69.0
17	"	6.4	51.5	83.0	73.5	69.0
18	"	6.6	49.5	83.0	73.0	69.0
19	"	6.8	49.5	83.0	73.0	69.0
20	"	7.4	49.5	83.0	73.0	69.0
21	"	7.8	49.5	81.5	72.5	69.0
22	"	8.0	48.0	81.5	72.5	69.0
23	"	"	48.0	81.5	72.5	69.0
24	"	"	47.5	81.5	72.5	69.0
25	"	"	47.0	81.5	72.5	69.0
26	"	"	46.5	81.5	72.5	69.0
27	"	"	46.5	80.5	72.5	69.0
28	"	"	46.5	80.5	72.0	69.0
29	"	"	45.5	80.5	72.0	69.0
30	"	"	45.0	80.5	71.5	69.0
31	"	"	45.0	80.5	71.5	69.0
32	"	"	45.0	80.5	71.5	69.0
33	"	"	45.0	80.5	71.5	69.0
34	"	"	45.0	80.5	71.5	69.0
35	"	"	44.5	80.5	71.5	69.0
36	"	"	44.5	80.5	71.5	69.0
37	"	"	44.0	80.5	71.5	69.0
38	"	"	44.0	80.5	71.5	69.0
39	"	"	44.0	80.5	71.5	69.0
40	"	"	43.5	80.5	71.5	69.0
41	60	"	43.5	79.0	71.5	69.0
42	"	"	43.0	79.0	71.5	69.0
43	"	"	42.5	79.0	71.5	69.0
44	"	"	42.5	79.0	70.5	70.0
45	"	"	42.0	79.0	70.5	70.0
46	"	"	41.5	79.0	70.5	70.0
47	"	"	41.0	79.0	70.5	70.0

COLUMN TEST NO. 4.-Continued.

Reading No.	Time Interval sec.	Head Readings ft.	Gauge Readings No.130	No.128	No.129	No.127
48	60	8.0	41.0	79.0	70.5	70.0
49	"	"	40.5	79.0	70.5	69.0
50	"	"	40.5	79.0	70.5	69.0
51	300	"	39.5	77.5	70.5	69.0
52	"	"	39.5	77.5	70.5	69.0
53	"	"	38.5	77.5	70.5	69.0
54	"	"	38.5	77.0	70.5	69.0
55	"	"	38.5	77.0	70.5	69.0
56	"	"	38.5	77.0	70.5	69.0
Height of gauges from base--			6.0"	21.5"	42.5"	67.0"

Temperature of room- 74 degrees F.
Time of mixing,Batch 1- 6 3/4 minutes.
Time of mixing,Batch 2-- 5 2/3 minutes.
Total time of mixing----18 1/4 minutes.
Time of filling and hoisting bucket--50 1/2 minutes.
Time of pouring column- ----- -------- 5 1/2 minutes.
Total time of observations---------- 50 1/4 minutes.

3 six inch cubes were made from Batch 1,to be tested after 30 days.

Weight of materials,in pounds-- ---------

Batch	Stone	Sand	Cement	Water	Total
1	825	512	235	150	
2	827	506	235	150	
	1652	1018	470	300	3440

Table No. 19.

COLUMN TEST NO. 5.

20 Inch Square Column. Saturday, Feb.7, 1914.

Reading No.	Time Interval sec.	Head Reading ft.	Gauge Readings No.130	No.128	No.129	No.56	No.127
1	15	0.0	16.0	64.0	46.0	64.5	64.5
2	"		16.0	64.0	46.0	64.5	64.5
3	"		16.0	64.0	46.0	64.5	64.5
4	"		16.0	64.0	46.0	64.5	64.5
5	"	1.7	16.0	64.0	46.0	64.5	64.5
6	"		16.0	64.0	46.0	64.5	64.5
7	"		16.0	64.0	46.0	64.5	64.5
8	"		16.0	64.0	46.0	64.5	64.5
9	"		16.0	64.0	46.0	64.5	64.5
10	"		17.0	64.0	46.0	64.5	64.5
11	"	2.0	18.5	64.0	46.0	64.5	64.5
12	"	2.5	20.0	64.0	46.0	64.5	64.5
13	"		22.5	64.0	46.0	64.5	64.5
14	"		23.0	64.0	46.0	64.5	64.5
15	"		24.0	66.0	46.0	64.5	64.5
16	"		24.5	66.0	46.0	64.5	64.5
17	"	3.5	26.0	69.0	46.0	64.5	64.5
18	"	4.7	27.0	70.0	46.0	64.5	64.5
19	"		29.0	70.0	46.0	64.5	64.5
20	"		33.5	73.0	47.0	64.5	64.5
21	"		35.5	75.0	49.0	64.5	64.5
22	"	5.0	38.5	77.0	51.5	64.5	64.5
23	"		41.0	79.0	53.5	65.0	64.5
24	"	6.0	43.0	81.0	56.0	67.0	64.5
25	"	7.0	46.5	85.5	59.0	72.0	64.5
26	"	7.5	46.5	87.5	59.5	74.0	65.5
27	"	7.6	46.5	88.5	59.5	75.5	67.5
28	"	8.3	46.5	89.5	60.5	77.0	70.0
29	"	9.0	46.5	90.5	62.0	78.5	71.5
30	"	10.0	46.5	90.5	62.5	78.5	72.0
31	"	11.0	44.0	90.5	62.5	78.5	72.0
32	"	11.5	42.5	90.5	62.5	78.5	72.0
33	"	12.0	41.5	90.5	62.5	78.5	72.0
34	"	"	40.0	90.5	62.0	78.5	72.0
35	"	"	39.0	90.5	61.0	78.5	72.0
36	"	"	38.0	90.5	61.0	78.5	72.0
37	"	"	37.0	89.0	60.5	78.5	72.0
38	"	"	36.5	89.0	60.5	78.5	71.5
39	"	"	36.0	89.0	60.5	78.5	71.0
40	"	"	35.0	89.0	60.5	78.5	71.0
41	"	"	34.5	89.0	60.5	78.5	71.0
42	"	"	34.0	88.0	60.5	78.5	71.0
43	"	"	33.5	88.0	60.5	78.5	71.0
44	"	"	33.0	88.0	60.5	78.5	70.5
45	"	"	33.0	88.0	60.5	78.5	70.5
46	60	"	32.0	88.0	60.5	78.5	70.5

COLUMN TEST NO. 5.-Continued.

Reading No.	Time Interval sec.	Head Reading ft.	Gauge Readings No.130	No.128	No.129	No.56	No.127
47	60	12.0	31.0	86.5	60.5	77.5	70.5
48	"	"	30.5	86.5	60.5	77.5	70.5
49	"	"	30.5	85.5	60.5	77.5	70.5
50	"	"	30.0	85.5	60.5	77.5	70.0
51	"	"	29.5	85.5	60.5	77.5	70.0
52	"	"	29.0	85.5	60.5	77.5	70.0
53	"	"	28.5	85.5	60.5	77.5	70.0
54	"	"	28.5	85.5	60.5	77.5	70.0
55	300	"	27.5	84.0	57.0	77.0	70.0
56	"	"	27.0	84.0	55.5	75.5	70.0
57	"	"	27.0	81.5	55.0	75.5	69.5
58	5940	"	25.5	73.0	51.5	71.0	69.5
Height from base of column			6.0"	21.5"	42.5"	67.0"	91.0"

Reading 58 taken 1 hr. 39 min. after reading 57.
Temperature of room- 63 degrees F.
Time of mixing,Batch 1 -- 5 1/4 minutes.
Time of mixing,Batch 2 - 3 1/2 minutes.
Time of mixing,Batch 3 -- 5 minutes.
Total time mixing concrete48 1/2 minutes.
Time of filling bucket----39 minutes.
Time of hoisting bucket-- 20 minutes.
Time of pouring column--- 9 1/2 minutes.
Total time of observations- 2 hrs. 14 1/2 min.
3 six inch cubes were made, to be tested March 7,1914.

Weight of materials, in pounds------

Batch	Stone	Sand	Cement	Water	Total
1	892	555	259	168	
2	900	550	259	168	
3	898	555	259	168	
	2690	1660	777	504	5631

Table No. 20.

COLUMN TEST NO.6.

20 Inch Square Column. Saturday, Feb.7, 1914.

Reading No.	Time Interval sec.	Head Reading ft.	Gauge Readings No.130	No.128	No.129	No.56	No.127
1	15	0.0	16.0	65.0	30.0	64.5	64.0
2	"	0.4	16.0	65.0	30.0	64.5	64.0
3	"	0.8	16.0	65.0	30.0	64.5	64.0
4	"		16.0	65.0	30.0	64.5	64.0
5	"	1.3	19.5	65.0	25.5	64.5	64.0
6	"	2.2	22.0	66.0	26.5	65.0	64.0
7	"	3.0	24.5	70.0	26.5	65.5	64.0
8	"	3.2	25.5	70.0	26.5	65.5	64.0
9	"	3.6	29.5	72.0	26.0	65.5	64.0
10	"	4.0	31.0	72.5	26.0	65.5	64.0
11	"		31.5	72.5	26.0	65.5	64.0
12	"		32.5	73.5	27.5	65.5	64.0
13	"	4.3	34.0	75.0	28.0	65.5	64.0
14	"	4.8	38.0	78.5	31.0	65.5	64.0
15	"	6.0	41.0	80.5	33.0	67.0	64.0
16	"	7.0	42.0	82.0	34.0	69.5	64.0
17	"	8.0	43.5	85.0	36.5	72.5	64.0
18	"	9.6	46.0	87.5	39.0	75.0	64.5
19	"	10.0	47.5	89.5	41.5	77.0	67.0
20	"	10.6	47.5	89.5	42.0	78.0	70.0
21	"	11.0	47.5	91.0	43.0	79.0	71.5
22	"	12.0	48.0	91.5	44.5	80.5	73.0
23	"	"	48.0	91.5	44.5	81.0	74.5
24	"	"	48.0	91.5	44.5	81.0	74.0
25	"	"	47.5	91.5	44.5	81.0	74.0
26	"	"	47.0	91.5	44.5	81.0	73.5
27	"	"	46.5	91.5	44.5	81.0	73.5
28	"	"	45.5	91.5	44.5	81.0	73.5
29	"	"	45.0	91.5	44.5	81.0	73.5
30	"	"	44.5	91.5	44.5	81.0	73.5
31	"	"	44.5	91.5	44.5	81.0	73.5
32	"	"	44.0	91.5	44.5	81.0	73.5
33	"	"	43.5	91.5	44.5	81.0	73.0
34	"	"	43.0	91.5	44.5	81.0	73.0
35	60	"	42.0	89.5	44.5	81.0	73.0
36	"	"	41.5	89.5	44.5	80.5	73.0
37	"	"	40.5	89.5	44.5	80.5	73.0
38	"	"	40.0	89.5	44.5	80.5	73.0
39	"	"	39.5	89.5	44.5	80.5	72.5
40	"	"	39.0	89.0	44.5	80.5	72.5
41	"	"	38.0	89.0	44.5	80.5	72.0
42	"	"	38.0	89.0	44.5	80.5	72.0
43	"	"	37.5	89.0	44.5	80.5	72.0
44	"	"	37.5	89.0	44.5	80.5	72.0
45	"	"	36.4	89.0	44.5	80.5	72.0

COLUMN TEST NO. 6.-Continued.

Reading No.	Time Interval sec.	Head Reading ft.	Gauge Readings No.130	No.128	No.129	No.56	No.127
46	300	12.0	35.0	86.5	44.5	79.0	72.0
47	"	"	34.5	86.5	44.5	79.0	72.0
48	"	"	34.5	86.0	44.5	79.0	72.0
49	"	"	34.0	85.0	38.5	79.0	72.0
50	"	"	33.5	84.0	38.5	79.0	72.0
51	"	"	33.5	84.0	38.5	79.0	72.0
52		"	20.5	74.5	19.0	67.5	66.5
Height from base of column			6.0"	21.5"	42.5"	67.0"	91.0"

Reading 52 taken 19 hr. 50 min. after reading 51.
Temperature of room- 63 degrees F.
Time of mixing, Batch 1 ---------4 1/4 minutes.
Time of mixing,Batch 2 -------- 4 1/4 minutes.
Time of mixing, Batch 3--------- 4 minutes.
Total time of mixing concrete 50 minutes.
Time of filling bucket--------- 33 1/4 minutes.
Time of hoisting bucket---------32 1/2 minutes.
Time of pouring column--------- 5 1/2 minutes.
Total time of observations-18 hr.39 minutes.
3 six inch cubes were made,to be tested March 7, 1914.

Weight of materials, in pounds----------

Batch	Stone	Sand	Cement	Water	Total
1	914	553	259	168	
2	897	538	259	168	
3	888	544	259	168	
	2699	1635	777	504	5615

Test No. 1.
Head-Pressure Curves
for
12-inch square Column Form
Consistency 9.2 %
Time of Pouring 6 min.
Temperature
February 5, 1914.

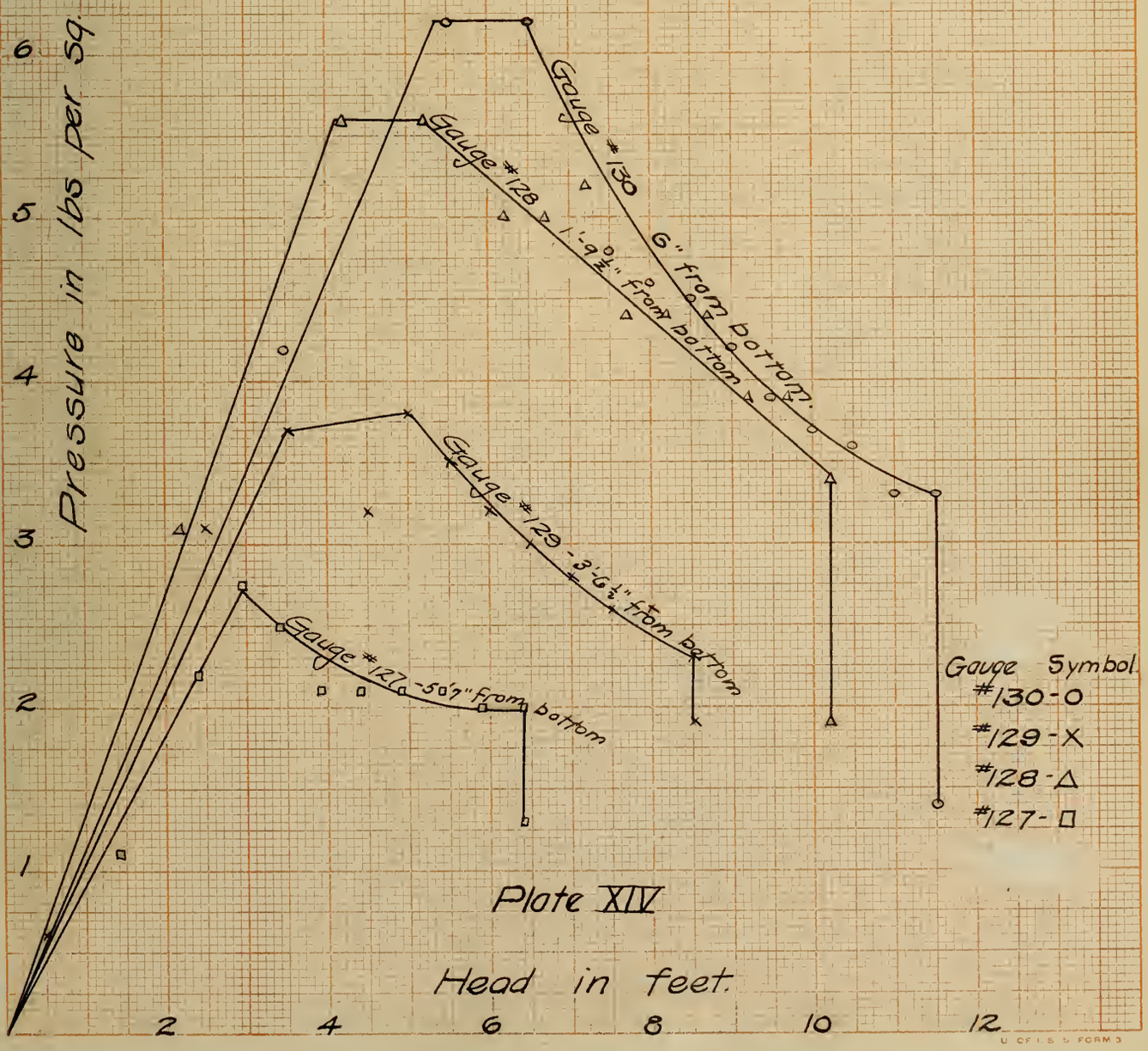


Plate XIV

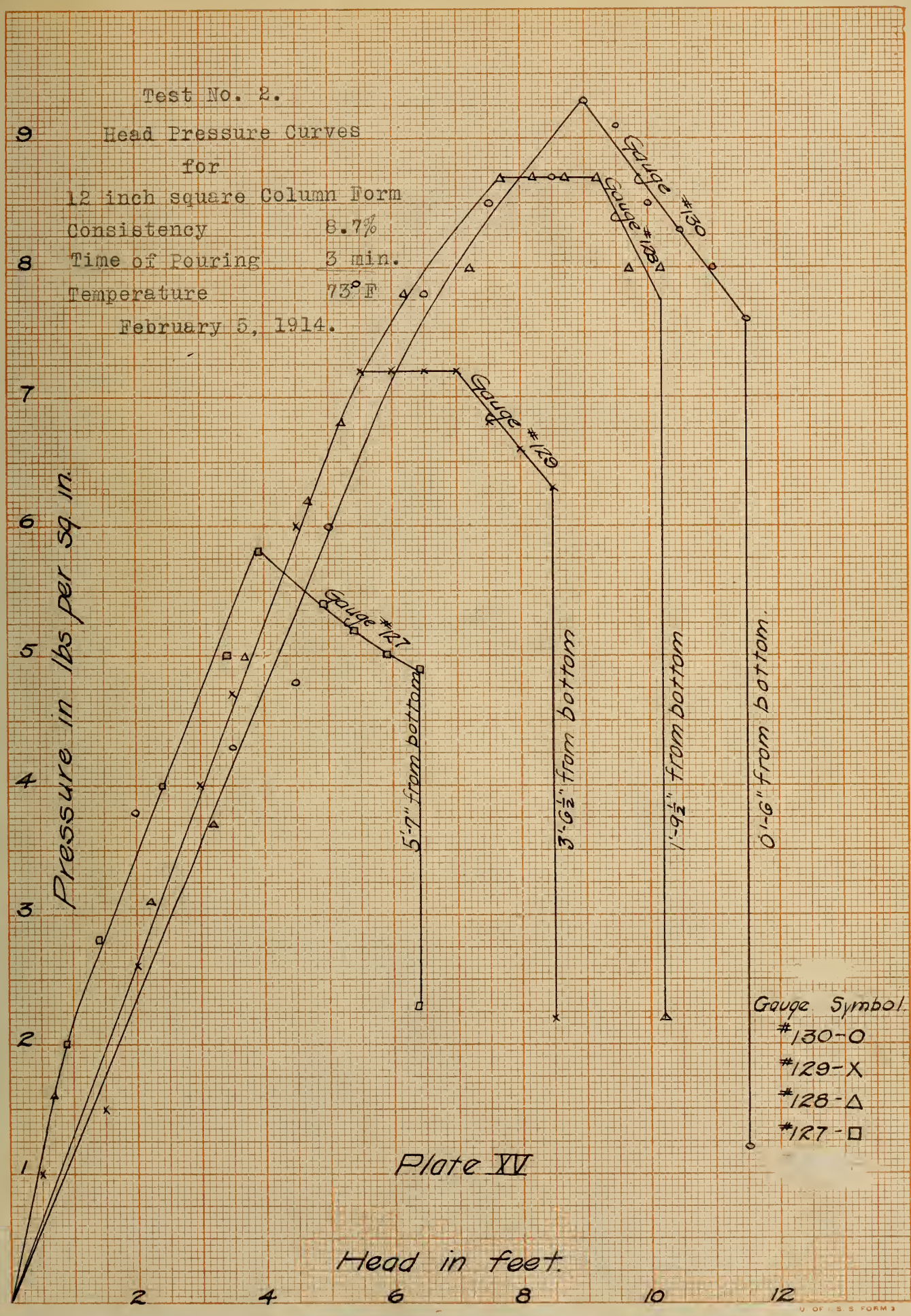

Test No. 2.
Head Pressure Curves
for
12 inch square Column Form
Consistency 8.7%
Time of Pouring 3 min.
Temperature 73° F
February 5, 1914.
Gauge #130
Gauge #128
Gauge #129
Gauge #127
5'-7" from bottom
3'-6½" from bottom
1'-6" from bottom
0'-6" from bottom
Pressure in lbs per sq in.
Head in feet.
Gauge Symbol
#130-O
#129-X
#128-△
#127-□

Plate XV

Test No 3.

Head Pressure Curves

for

12 inch square Column Form

Consistency- 9.3%

Time of Pouring 9 min.

Temperature 72° F

February 6, 1914.

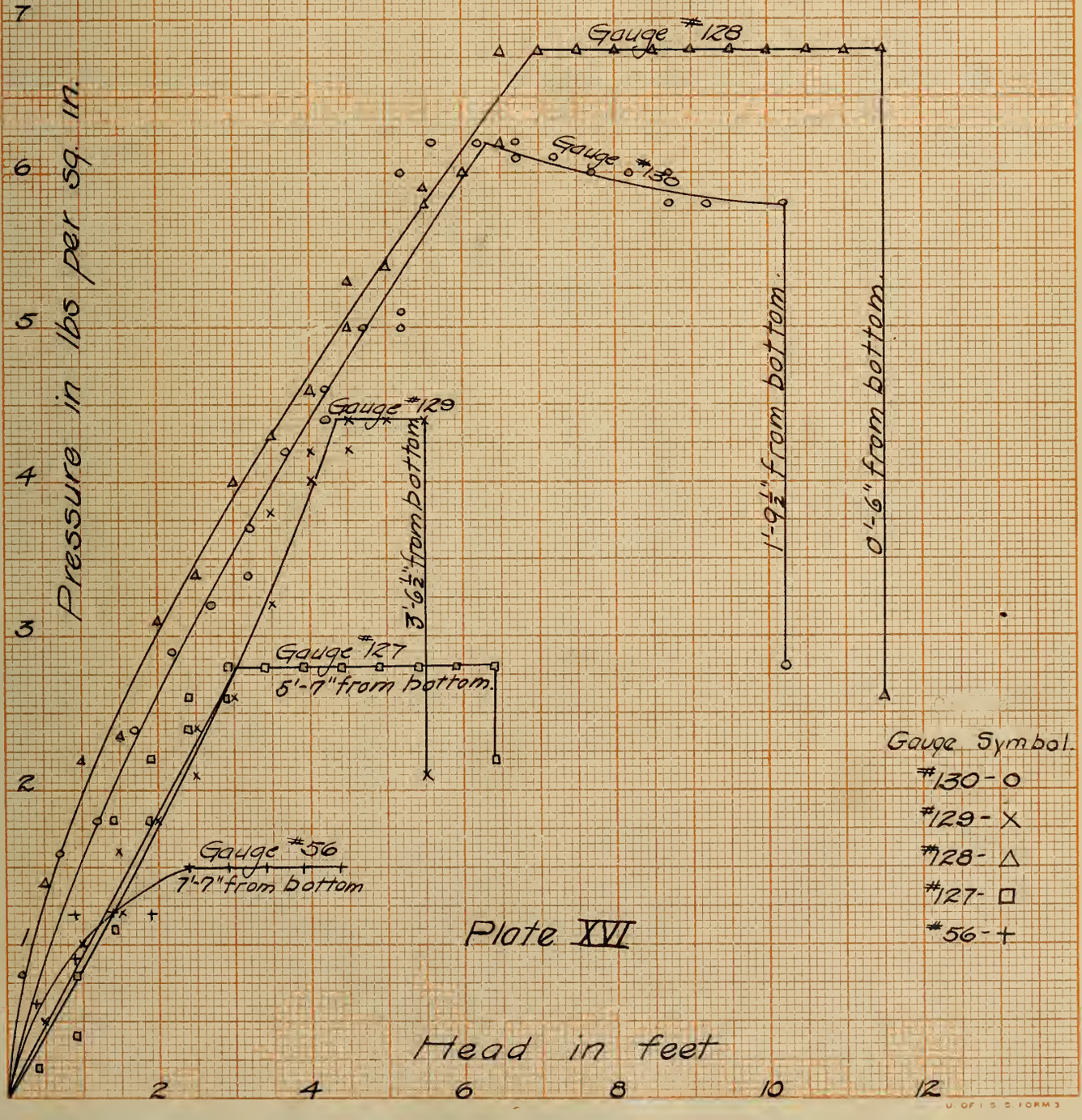


Plate XVI

Test No. 4.

Head Pressure Curves

for

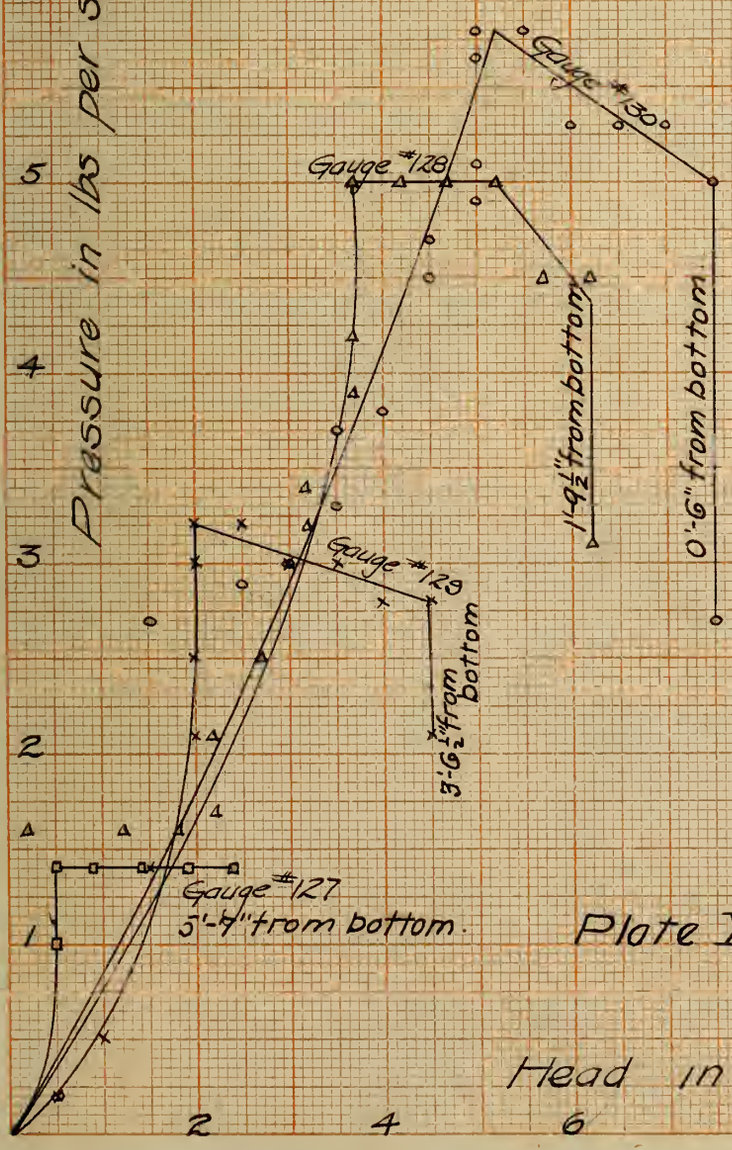
20 inch square Column Form

Consistency 9.5%

Time of Pouring 5.5 min.

Temperature 74° F

February 6, 1914.



Gauge Symbol

#130- O

#129- X

#128- Δ

#127- □

Plate XVII

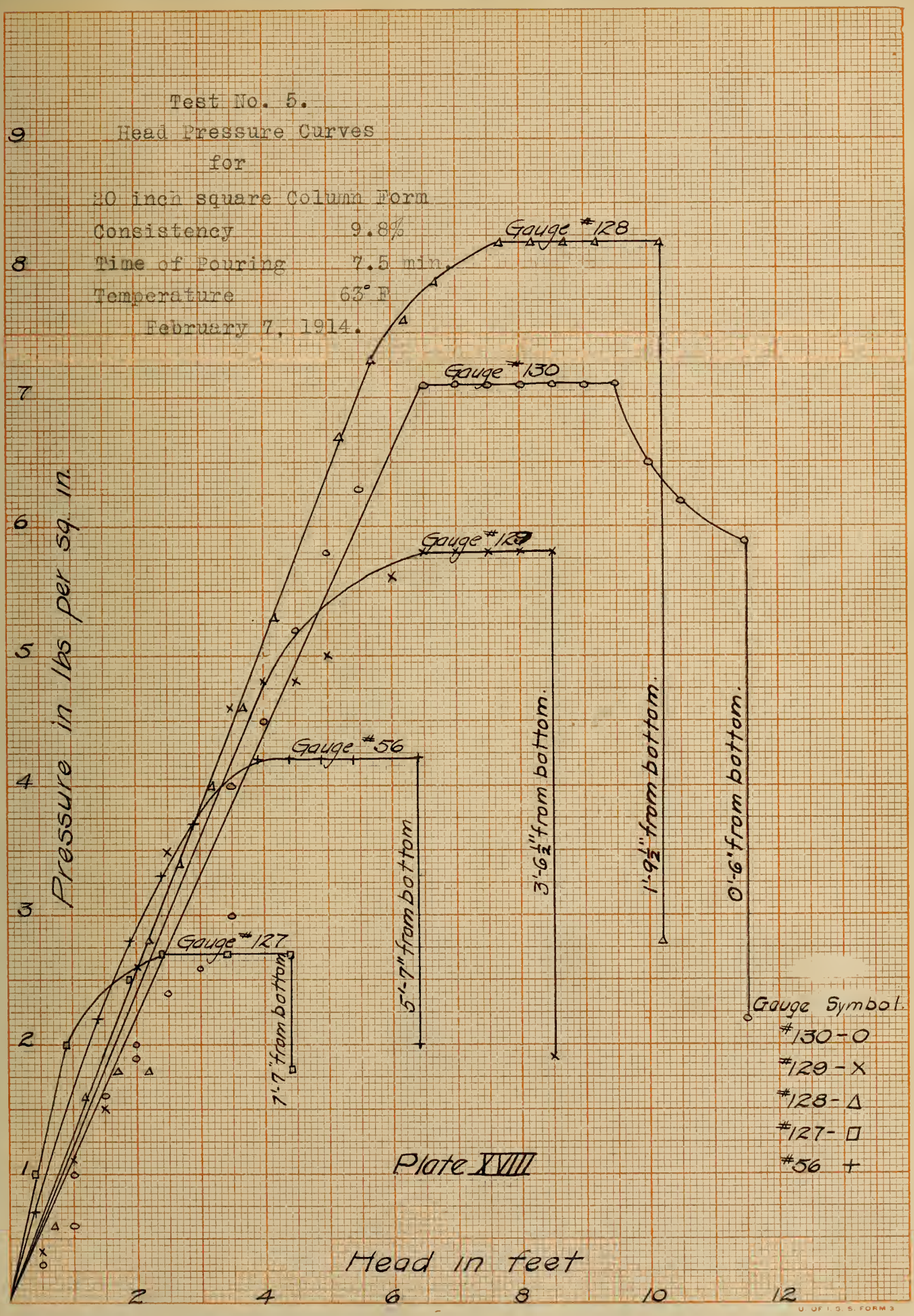

Test No. 5.
Head Pressure Curves
for
20 inch square Column Form
Consistency 9.8%
Time of Pouring 7.5 min.
Temperature 63° F
February 7, 1914.
Gauge #128
Gauge #130
Gauge #129
Gauge #56
Gauge #127
1'-7" from bottom
5'-7" from bottom
3'-6½" from bottom.
1'-9½" from bottom.
0'-6" from bottom.
Gauge Symbol
#130 - O
#129 - X
#128 - Δ
#127 - □
#56 +
Pressure in lbs per sq. in.
Head in feet
1
2
3
4
5
6
7
8
9
2
4
6
8
10
12

Plate XVIII

Test No. 6.

Head Pressure Curves

for

20 inch square Column Form

Consistency 9.0%

Time of Pouring 5.5 min.

Temperature 63° F

February 7, 1914.

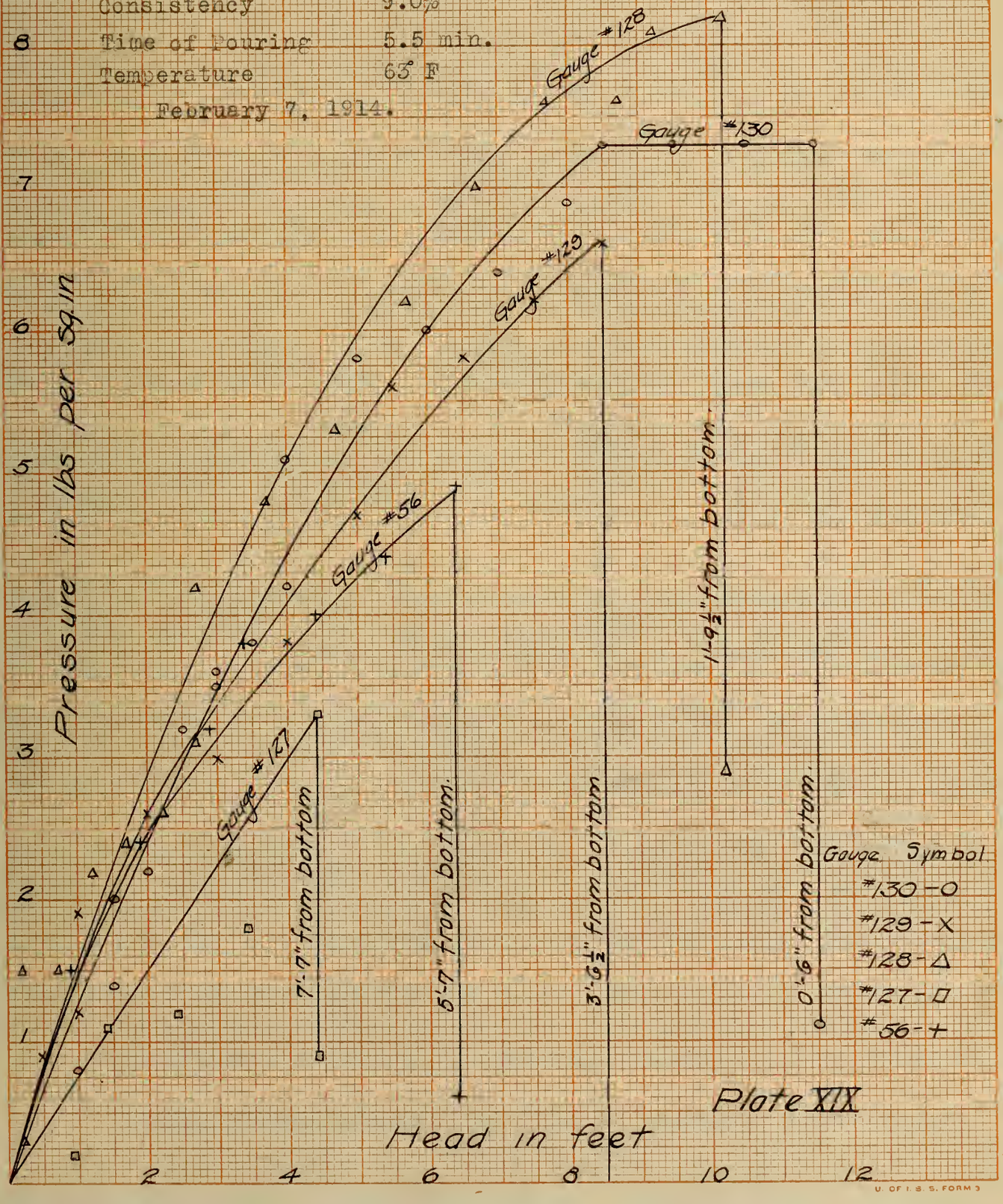


Plate XIX

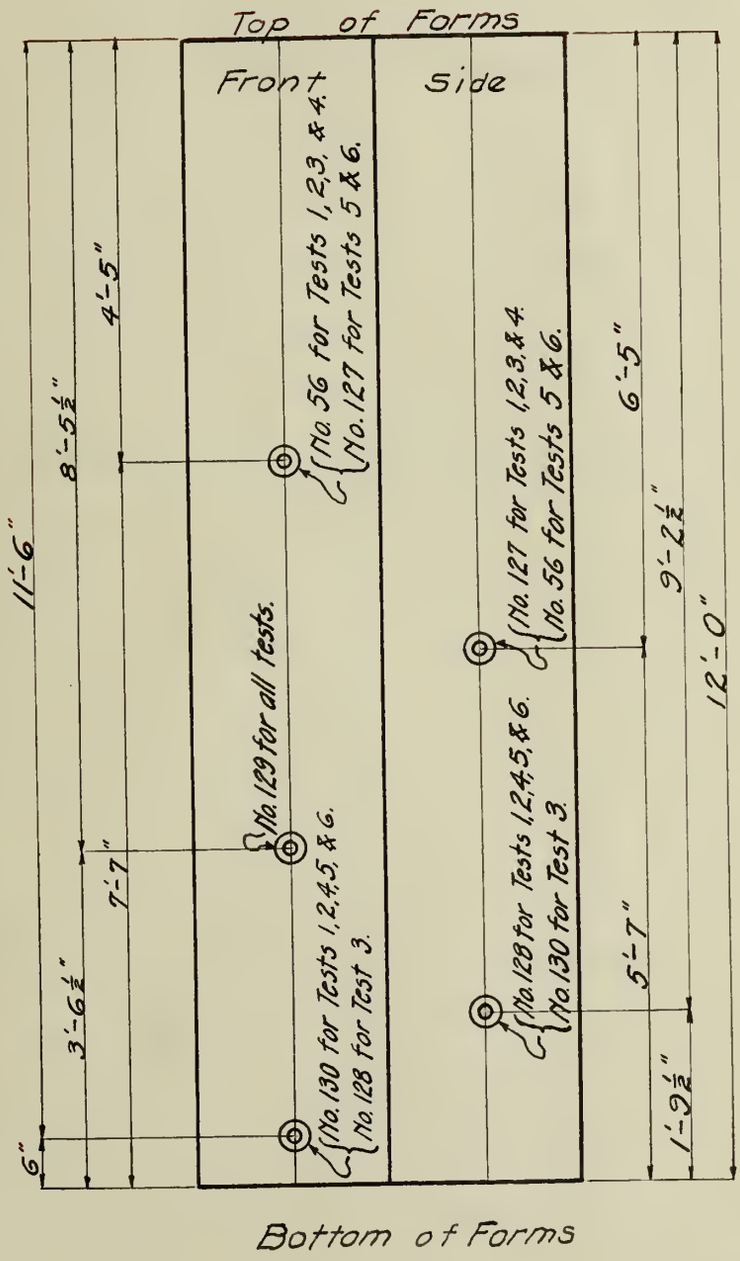


Diagram Showing Position of Gauges in Column Forms.

feet per second. Hence in one second the total pressure due to impact is equal to $\frac{0.145 \times 27.8 \times 150}{32.2}$ = 18.8 lb. This pressure would be distributed over at least a six-inch square surface so that the maximum possible pressure per square inch, due to this cause, was about 0.5 lb. This effect varies as the square root of the head, becoming zero at the top. Most of the curves are slightly convex toward the pressure axes which indicates that the impact may have had considerable effect. Therefore the pressures due to the higher heads, where the distance fallen thru was small, are probably more correct for slower rates of pouring.

2. Effect of the Size of Column- From a comparison of the pressures obtained in tests 1 and 6, it is evident that the size of the column affects the intensity of the lateral pressure against the forms. In test 1, a twelve-inch column form was used and the rate of pouring was two linear feet per minute. The maximum pressure on the lower gauge, number 130 (see page 58a), was 6.2 pounds per square inch. Test 6, however, of the 20-inch column was under almost the same conditions for it had a rate of pouring of 2.18 linear feet per minute. This larger column gave a maximum pressure, on the same gauge, of 7.3 pounds per square inch, which was 1.1 pounds per square inch higher than that of the 12-inch column, or an increase of 17.8 percent. The other gauges showed a similar increase. Gauge number 129 had readings of 3.8 and 6.6 pounds per square inch in the respective columns, and gauge number 127 had readings of 2.75 and 3.3 pounds per square inch. The lower pressure in the smaller column was undoubtedly due to the arch

action of the wet concrete preventing the entire head from reaching the lower gauge. The larger column, having a cross-sectional area of nearly three times that of the smaller, did not permit of as much arch action.

3. Relation of Lateral Pressure to Hydrostatic Pressure. The consistency of the concrete used was in all cases wet, and ranged from 8.7 to 9.8 per cent. Under these conditions the lateral pressure exerted corresponded somewhat closely to fluid pressure. The average maximum lateral pressure recorded by the bottom gauge in each of the six tests was that due to a liquid weighing 147 pounds per cubic foot, the range being from 159 to 124 pounds per cubic foot. According to the best information available the concrete weighed about 150 pounds per cubic foot. At the lower heads the pressures ran above fluid pressure, due to the effect of impact. Test 2, which was poured at the rate of 4 linear feet per minute, gave pressures for 1-ft. heads which would be caused by a liquid averaging 215 pounds per cubic foot.

4. Heads giving Maximum Pressures. The lateral pressure of gauge 130 increased up to a head of 9.0 feet in test 2, where the rate of pouring was the highest, viz., 4 linear feet per minute. The other tests gave maximum lateral pressures on all the gauges at lower heads. In test 4 this effective head on gauge 130 was as low as 5.2 feet when the rate of pouring was 1.5 linear feet per minute, and the average effective head of all tests for this gauge was 6.8 feet. These results are cited for gauge 130, the bottom gauge, because the heads were higher and the readings were more consistent on this gauge. The other gauges gave results of a similar character as may be seen by reference to figures XIV to XIX.

At the heads giving maximum lateral pressures, the cohesion in the concrete and its adhesion to the forms overcame the effect of the steadily increasing head, and the arch action supported the superinposed head.

5. Decrease of Pressure. In each test the pressure increased up to a certain maximum point. In most cases this pressure remained constant for an appreciable time and then gradually decreased. Note especially the curves on pages 53, 55, and 57. Readings were taken after the pouring was completed in order to determine the amount of decrease in pressure due to a gradual compacting and slight initial setting of the concrete. Values showed a decrease in pressure down to an average of about 2 pounds per square inch, or the corresponding pressure of a liquid weighing 25 pounds per cubic foot. In two instances, tests 5 and 6, the concrete was allowed to set thoroughly in the column forms, when the pressures lowered to averages of 1.9 and 0.6 pounds per square inch, respectively.

V. SUMMARY.

We may state in conclusion that:

(1) The lateral pressure increases with the effect of impact, which varies as the rate of pouring.

(2) The lateral pressure increases with the cross-sectional area of the column.

(3) The lateral pressure in general corresponds to hydrostatic pressure for wet concrete.

(4) The lateral pressure is a maximum at heads ranging up to 9 feet, depending on the rate of pouring and cross-sectional area of the column.

(5) The lateral pressure gradually decreases after a maximum value has been reached.

The above conclusions should be considered solely within the limits of these tests.